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*ON THE CHARACTER AND EFFECT OF THE ILLUMINANTS PRESENT IN COAL GAS.**

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COMMON coal gas consists of two distinct classes of bodies,—the illuminants or light-givers, and the diluents or light-bearers. These diluents consist of certain combustible carbon compounds and hydrogen, which, in burning, influence the temperature of the flame, but have comparitively little illuminating power. The prominent diluents are hydrogen, marsh gas, and carbonic oxide. These constitute most of the volume of gas, while the illuminants seldom constitute more than 6.5 per cent of the total volume. It would seem that the attention of gas chemists would have been directed to the examination of the bodies classed under the head of illuminants, but a study of the literature relating to gas shows that the difficulties connected with this question have generally deterred examiners from anything more than the estimation of the total volume of the illuminants. The analyst has usually contented himself with the determination of the volume per cent of the gas absorbed by strong sulphuric acid, and this quantity is commonly known as the percentage of illuminants. The assumption sometimes made that two gases having the same percentage of illuminants, and all other constituents ought to have the same candle-power, does not appear to be borne out by experience, and is erroneous from a theoretical point of view, as will be seen.

* From an address delivered before the New England Association of Gas Engineers, Feb. 20, 1889.

In the hope of throwing further light upon the nature and effect of these bodies, in connection with Mr. O. S. Doolittle, I undertook an examination of the Boston gas.

The illuminants present in coal gas consist of ethylene, propylene, acetylene, benzol, toluol, crotonylene and other hydrocarbons. The following table shows that such hydrocarbons as act as illuminants are relatively rich in carbon.

TABLE I.

CERTAIN CONSTITUENTS OF COAL GAS AND NAPHTHA GAS.

	Symbol.	Carbon.	Hydrogen.	Condition at the Ordinary Temperature.
Illuminants.				
Ethylene	C_2H_4	85.71 per ct.	14.29 per ct.	Gas.
Propylene	C_3H_6	85.71 "	14.29 "	Gas.
Amylene	C_5H_{10}	85.71 "	14.29 "	Liquid.
Hexylene	C_6H_{12}	85.71 "	14.29 "	Liquid.
Crotonylene	C_4H_6	88.80 "	11.20 "	Liquid.
Acetylene	C_2H_2	92.30 "	7.70 "	Gas.
Benzol	C_6H_6	92.30 "	7.70 "	Liquid.
Toluol	C_7H_8	91.30 "	8.70 "	Liquid.
Pentane	C_5H_{12}	83.33 "	16.67 "	Liquid.
Hexane	C_6H_{14}	83.72 "	16.28 "	Liquid.
Diluents.				
Marsh Gas	CH_4	75.00 "	25.00 "	Gas.
Ethane	C_2H_6	80.00 "	20.00 "	Gas.
Carbonic Oxide	CO	42.85 "	—	Gas.

In addition to the hydrocarbons mentioned above, naphthalene has been found a few times in coal gas. When this hydrocarbon is present it undoubtedly adds largely to the candle power of the gas; it contains 93.75 per cent of carbon and 6.25 per cent of hydrogen, and has been used as an artificial enricher at the burner.* It is the prevailing opinion that the value of any hydrocarbon as a light-giver, increases with the percentage of carbon present. In that case, it will be seen that benzol and acetylene are the most desirable illuminants.

Benzol was first found in illuminating gas by Faraday.† Pitschke‡

* English Patent, 10,778, June 10, 1886. † Philos. Trans., 1825.
‡ Jour. f. prak. Chem., 67, 415.

isolated and identified it in 1856. Berthelot * in 1876, in the course of his investigation of the Paris gas, found that it contained from 3 to 3.5 volume per cent of benzol. Since that time chemists have more and more inclined to the view that this is the most important substance present in gas. It appears to be always accompanied by a small quantity of toluol. Crotonylene was first found in illuminating gas by Caventou † in 1873, and as it almost invariably formed by the action of heat on petroleum naphthas,‡ it is probable that in coal gas enriched by naphtha, this illuminant plays a very important part. Amylene and hexylene may reach illuminating gas from the same source, while pentane and hexane are the important illuminants in gasoline gas. The quantity of acetylene present appears to be very minute.

The examination of the character of illuminants by the ordinary methods of gas analysis seemed unadvisable, on account of the minute quantities of certain substances present. In fact, Treadwell and Stokes § have lately pronounced it impossible to determine the amount of benzol in illuminating gas by ordinary methods of gas analysis.

We therefore worked with considerable volumes of gas, and used from fifteen to forty cubic feet.

Ethylene and Propylene.

We removed these substances from the gas by absorption with bromine. The bromides thus obtained by the union of the bromine with the gases were distilled in vacuo and fractionated, and after analysis the per cent of the substances in the original volume calculated. The liquid bromides of ethylene and propylene left upon distillation in vacuo a solid residue which was purified by crystallization and found to consist of crotonylene tetrabromide and dibrombenzol. These were separated by crystallization and examined.

Benzol.

We attempted to absorb the benzol in nitric acid, but we soon became convinced that this method was unsatisfactory. We then undertook to remove the liquid hydrocarbons from the gas by passing it through olive oil, as suggested by Ditmar and Davis.‖ We found this method to be an excellent one, and we passed thirteen feet of gas slowly through the oil. We then heated the oil and passed steam through it. The steam carried over the liquids absorbed from the gas, and after con-

* Ann. d. Chim. et Phys., 5, 10, 169. † Ber. d. Chem. Gesell., 6, 70.
‡ Norton and Andrews, Am. Chem. Jour., VIII. 1.
§ Ber. d. Chem. Gesell., 21, 3131. ‖ Jour. Soc. Chem. Ind., 1886, 4.

densing the vapors, we separated the hydrocarbons from the water and examined them. They consisted largely of benzol and toluol. The olive oil probably absorbed the crotonylene also, but on account of its extreme volatility we were unable to condense it when the oil was treated with steam.

ACETYLENE.

Acetylene has been found in coal gas by Berthelot and others,* and he founds upon the fact an elaborate theory † regarding the formation of benzol in the retort. To determine the amount of acetylene, we passed the gas through subchloride of copper solution, which absorbs it readily, filtered off the red precipitate containing the acetylene, decomposed this with hydrochloric acid, and again absorbed the acetylene in bromine and weighed the tetrabromide formed.

NAPHTHALENE.

It would seem likely from the occurrence of naphthalene in tar and its occasional deposition in pipes, that this substance would be likely to be present in the gas. We attempted to find it by passing the gas through alcohol, in which it is very soluble, but the alcohol failed to remove a trace of it from the gas. Pitschke ‡ succeeded in finding naphthalene in gas by this method. We then tried to remove it by means of heavy petroleum naphtha, but did not succeed in obtaining a trace of it. We next had recourse to cold and pressure, and subjected the gas under a pressure of five atmospheres to a temperature of $+9°$ F., but only succeeded in condensing liquid hydrocarbons. In one case only, among the solids obtained by the action of bromine upon the gas, we obtained a small quantity of a substance which may have been dibromnaphthalene.

OTHER CONSTITUENTS.

The oxygen, nitrogen, carbonic acid, carbonic oxide, and marsh gas were determined in the ordinary way with the Hempel gas apparatus. The specific gravity was determined by weighing a known volume in a flask.

The following table shows the composition of the sample of Boston gas, and also contains all the other complete analyses of coal gas which I have been able to find.

* Böttger, Landolt, Blochmann, Fischer.

† Compt. rend., 50, 805 and 62, 94. Ann. d. Chem. et Phys., 4, 16, 144. See also, Jacobsen, Ber. d. Chem. Gesell., 10, 853.

‡ *Loc. cit.*

TABLE II.

ANALYSES OF COAL GAS, IN VOLUME PER CENT.

	I.	II.	III.	IV.	V.	VI.	VII.
Ethylene	2.30	2.01	2.55	2.48	2.11	2.24	0.1–0.2
Propylene	0.73	0.72	1.21	0.64	0.37	—	0.02
Benzol	0.83	0.66	0.69	0.59	0.69	2.00	3.0–3.5
Acetylene, Crotonylene, etc.	2.17	—	—	—	—	—	0.1
Carbonic Acid	0.12	1.40	3.01	0.48	0.81	2.94	—
Carbonic Oxide	6.08	4.00	8.88	7.42	11.19	6.00	—
Marsh Gas	42.32	35.28	34.02	38.75	46.27	41.50	—
Hydrogen	35.35	52.75	46.20	47.60	37.55	45.70	—
Oxygen	0.12	—	—	0.02	—	—	—
Nitrogen	9.98	3.18	2.15	2.02	1.01	—	—
Specific Gravity	0.41	0.37	—	—	—	—	—

I. Boston gas, by Norton and Doolittle. — II. Königsberg gas, by Blochmann.* — III. Heidelberg gas, by Kinnicutt and Treadwell.† — IV. and V. Hanover gas, by Fischer.‡ — VI. Manchester (Eng.) gas, by Davis.§ — VII. Paris gas, by Berthelot.‖

So far as I am able to learn, these samples are all pure coal gas, with the exception of the Boston gas, which is enriched by naphtha. It will be observed in the table presented that in general, the percentage of ethylene remains nearly constant, that of propylene varies somewhat more, while that of benzol undergoes still greater variations. Besides these illuminants, the Boston gas contained other illuminants, consisting of acetylene, a considerable amount of crotonylene, and small quantities of hexylene and amylene, making up some 2.17 per cent of the total volume.

CANDLE POWER.

The next question to be considered is naturally, which of these illuminants has the most value in giving illuminating power to the flame.

In order to gain some information upon this point the Boston gas was passed through olive oil to remove its liquid constituents, and the loss in candle power caused by a removal of these determined. We found the mean of three determinations of the gas as received to be 18.27 candles, and after passage through the oil to be 7.03 candles, show-

* Ann. d. Chem., 207, 177. † Bunsen, Gasometrische Methoden, 1877, p. 142.
‡ Die Chemische Technologie der Brennstoffe, 1887, p. 290.
§ Jour. Soc. Chem. Ind., 1883, 71. ‖ Ann. d. Chim. et Phys., 5, 10, 169.

ing that 61.6 per cent of the illuminating power of the gas was due to the liquid hydrocarbons. Knoblauch * several years ago found by experiment that the illuminating value of benzol vapor was about six times that of ethylene, and P. F. Frankland † arrives at the same conclusion, and finds that pure ethylene has a candle power of 68.5 candles, calculated upon the basis of a consumption of 5 ft. per hour. This would give benzol vapor a candle power of 411.0, and it immediately becomes apparent that a very small quantity of benzol vapor can exert an important influence upon the gas. Frankland found that a mixture of marsh gas and hydrogen must have 13.4 per cent of ethylene added to it to reach 16.8 candles, while 3.09 per cent of benzol vapor gave a candle power of 22.9 candles. From the point of view of weight, however, benzol vapor possesses a much smaller advantage over ethylene, and would have only 2.1 times the candle power of ethylene for equal weights.

It is greatly to be regretted that no figures exist regarding the effect of propylene, acetylene, crotonylene, and amylene as illuminants. There is a prevailing opinion that these compounds all have a much greater effect than ethylene, but it cannot be said to be based upon experiment. But it can safely be asserted that benzol is the most valuable of the illuminants, and that its presence is to be desired in illuminating gas in the largest quantity which will not cause inconvenience by condensation in the pipes. Davis, ‡ at a time when benzol commanded a higher price than at present, proposed to remove it from gas, and, if necessary, replace it by other and cheaper illuminants. In the course of his investigations he found the following hydrocarbons present in coal gas produced at private works, viz.: pentane, amylene, crotonylene, hexane, hexylene, benzol, hexine, heptanes, heptylene, octane, octylene, nonane, nonylene, xylol, toluol, and naphthalene. Three-quarters of the liquid present which could be condensed consisted of benzol.

WEIGHT PERCENTAGES.

While the quantities of benzol and other illuminants present in gas as shown by Table II. are small, the per cents by weight, on the other hand, are much larger. The following table shows the per cent by weight of the most important constituents of three samples of gas.

* Schillings Jour. f. Gasbel. u. Wasserversorg., XXIII. 274.
† Jour. Soc. Chem. Ind., 3, 279. ‡ Jour. Soc. Chem. Ind., 2, 522.

TABLE III.

WEIGHT PERCENTAGES.

	I.	II.	III.
Ethylene	5.4	5.1	5.0
Propylene	2.5	2.7	—
Benzol	5.4	4.7	12.5
Carbonic Oxide	14.1	22.7	13.0
Hydrogen	5.9	9.7	7.1
Marsh Gas	57.2	51.7	52.0

I. Boston gas, by Norton and Doolittle. — II. Königsberg gas, by Blochmann. — III. Manchester (Eng.) gas, by Davis.

These figures, which are only approximations, show that from this point of view the illuminants, instead of constituting from four to six per cent as by volume, constitute from twelve and five-tenths to seventeen and five-tenths per cent by weight.

TAR.

The amount of benzol which passes into the tar is relatively small, while the quantity of toluol and xylol is relatively much greater in comparison with the total amount formed. We found in the Boston tar 0.39 per cent of benzol, 0.35 per cent of toluol, and 0.16 per cent of xylol. Figuring now upon a basis of 4.5 per cent of tar and 9000 cubic feet of gas to the ton of 2000 pounds, we have roughly one-half of one pound of commercial benzol in the tar, and sixteen pounds of benzol in the gas. These figures agree approximately with those obtained by the Paris company, who, in ten years, found that one twenty-fourth of the benzol went into the tar.*

ENRICHERS.

The best enrichers to use would then appear to be those substances, which, upon decomposition, will give a gas containing a high per cent of benzol or other liquid illuminant. The cannel coal is ordinarily sure upon decomposition to furnish some benzol, and also to furnish gas of high candle power. In regard to the composition of the gas obtained by heating cannel coal, very little, in fact almost nothing, appears

* Lunge, Coal Tar and Ammonia, 1887, p. 31.

to be known. A few experiments of my own upon the composition of gas furnished by the decomposition of albertite at a high temperature give all the information that I have been able to gain in this direction, as far as the nature of the illuminants is concerned. The decomposition of albertite at a high temperature gives rise to gas of high candle power. In the experiments which I made, I found that it contained about 27 per cent of illuminants, and its illuminating power was four times that of the Boston gas. The sample that I examined gave upon destructive distillation almost no ethylene; but propylene was found to a very considerable extent, as were also hexylene and amylene. So that under the circumstances in which I heated albertite it gave rise to very little ethylene and comparatively little benzol, but mainly hydrocarbons of the ethylene type, consisting of propylene, hexylene, and those of about that composition and character. Naphtha is much more uncertain in its action. It has been shown * that at a moderate red heat, naphtha furnishes very little benzol, and that crotonylene, amylene, and hexylene must be largely relied upon under such circumstances to raise the candle power. Naphtha furnishes ethylene and propylene with great ease upon heating. On the other hand, Moore † in his investigation upon the Granger Water Gas Process, found from 1.5 to 2.6 volume per cent of benzol vapor formed, he states, by the heating of the water gas and naphtha vapor together. The heavy oils, such as residuum and crude oil, upon decomposition, produce doubtless benzol more easily than naphtha does, and yet there is little data regarding this matter. My own experiments have been confined to naphtha.

In regard to the use of heavy oils, such as residuum and crude oil, as stated, there is doubtless more benzol produced in the decomposition of residuum than in that of naphtha; but the only experiments which bear upon this relate especially to the residuum of Russian petroleum.‡ Unfortunately the Russian petroleum contains compounds belonging to the benzol class; so that the results of these experiments are not as definite as we might wish. A considerable yield of benzol was obtained from the decomposition of residuum — a considerably greater yield than can be obtained from naphtha.

Tar has been recommended as an enricher, perhaps on the ground that it contained benzol. Tar undoubtedly does contain a very considerable percentage of hydrocarbons belonging to the benzol series, and

* Norton and Andrews, Am. Chem. Jour., VIII. 1.

† Report on the Granger Water Gas, Phil., 1885.

‡ Letny, Ber. d. Chem. Gesell., 11, 1210.

these compounds, upon decomposition, give rise to benzol. The amount of such compounds is perhaps 12 to 15 per cent of the total weight of the tar; so it is conceivable that, by a proper use of the tar, a gas of high candle power, containing benzol, might be obtained, but the volume would not be large.

A PRELIMINARY PAPER ON THE DRIFT IN PORTIONS OF MIDDLESEX COUNTY.

BY GEO. H. BARTON.

As the title of this paper indicates, it is but a preliminary paper. It embraces the results of field observations made by the writer during portions of the summer of 1888. The territory examined all lies within a short distance of the Fitchburg railroad or its branches, and comprises in whole or in part the towns of Stow, Maynard, Sudbury, Acton, Concord, Lincoln, and Weston. It is expected that during the coming summer not only that a much larger area to the westward will be investigated, but that the ground already traversed will in all places of especial interest be studied with much greater care than is possible in the first preliminary survey.

It is now very well understood that the drift, which was accumulated in its present form by the action of the ice-sheet which spread over the northern portions of the United States during the glacial period, and was derived very largely from the loose material which had previously been formed by the mechanical and chemical disintegration of the rocks near the surface of the earth, is divided in general into three main divisions, viz., the lower, upper, and modified drift, or till, as it is sometimes called.

The first or lower till is that which accumulated below the mass of the ice and was hardened and compacted by the immense weight of the ice-sheet. The bowlders contained in the lower till are more or less subangular or rounded and are usually somewhat marked with striations. The general mass of this till is usually spoken of as largely made up of blue clay, but recent investigations by Prof. W. O. Crosby have shown that the percentage of true clay is very small, and that the larger proportion of the fine material consists of silica, some of it ground to the fineness of a flour.

The upper till is that portion which remained upon the surface of the ice or was incorporated in its mass and was left as a somewhat thin mantle over the entire surface of the country as the ice melted from under it. The bowlders contained in this are but little if any rounded, being generally quite angular.

The modified till resulted from the action of the waters produced by

the melting of the ice-sheet upon the materials of both the upper and lower till, but principally upon that of the former. The sorting power of the water separated the materials according to their degrees of fineness or specific gravity. The larger fragments were left as beds of coarse gravel, the quartz grains accumulated to form the sand plains, while the finer material, the clay, was carried farther away to form clay beds in the marshes near the sea and other low places.

The most prominent objects in the topography of this portion of the glaciated area connected with the drift are the drumlins, or somewhat lenticular hills, formed principally of the materials of the lower drift.

The upper drift has no features of striking peculiarity. In the modified drift the principal and most noticeable features are the sand plains that have accumulated along the valleys of the streams, and also in large masses over considerable areas of the comparatively level surface of the country. Associated with these often are those peculiar structures known as kames, which are long, narrow ridges of pebbles of all sizes up to a foot and sometimes more in diameter, and all well rounded and water-worn. These ridges conform generally to the surface upon which they rest, often extending for long distances over comparatively level surface, sometimes winding along up the sides of a hill, often following along the valley of a stream, but often leaving the valley when its trend changes from the general direction of the kame. In general the kames run north-south, but the direction may change many degrees to the east or west. Often they are very winding or serpentine, and sometimes form complete horseshoe curves. Sometimes they run in single lines, sometimes in a series of ridges nearly parallel to each other.

Taking up the phenomena mentioned and in the same order, we find in the region under discussion that drumlins are numerous in the towns of Stow and Maynard, and in the southern half of Acton, scattering in Sudbury and Concord, and very rare in Lincoln and Weston.

In Stow they are most noticeable in the southeast portion of the town, along or near the Assabet River. The one farthest to the west, just west of the village of Rockbottom, is a double one, of which the portion to the west does not extend so far north, but much farther south, than the more easterly one. The easterly one has a peculiar channel cut through the summit just west of the crest and parallel to the longer axis of the hill. The depth of this channel varies from fifteen to twenty feet. The longer axis of the hill, which much exceeds its shorter axis, has the direction N.–10–W. Its slope to the east varies from 8° to 25°, the latter being an unusually steep one for hills of this class.

Next to the east is Sugar Loaf, which has a very steep slope to the southward and a very gentle one to the north, giving a peculiar outline, differing from the majority, which are generally symmetrical. This hill has its longer axis N.–S. Just south of Whitman's Station on the branch of the Fitchburg railroad is Boon's Hill, which is nearly circular in plan and comparatively low in contour. Northwest of this and on the north side of Assabet River is Priest's Hill, a much higher elevation, somewhat composite in form, but not distinctly divided into more than one summit. Still again to the northwest, in the same general trend as the two latter hills, and just south of the main road from Stow to Bolton, is Spindle Hill, a well-marked, typical drumlin, with longer axis about N.–10–W. South of the river, about half-way between Whitman's and Maynard, is a group of three hills, the most easterly of which is of rock, while the other two are drumlins. The central hill is partially superimposed upon the rock hill and has its longer axis about N.–S., while that of the westerly hill of the group is N.–60–W., thus lying at a large angle with the former. These hills are thickly covered with bowlders, some of which reach a diameter of fifteen feet. Opposite these, on the north side of the river, is a drumlin thickly covered with wood which has not been examined. South of the river, and on the boundary line between Stow and Maynard, are two very large hills very much elongated, but with axes very different in direction, one lying nearly across the trend of the other. The northerly one has the longer axis a little west of north, the southerly N.–10–E.

Directly north of the river is a hill which is not prominent, with its axis still more inclined to the east. Northeast of this latter elevation is the most remarkable series yet studied in this area. From the north or south it has the appearance of a very large drumlin with a very long axis extending nearly east and west. On the summit, however, it at once shows its true character, where it is readily seen that it consists of a series of drumlins, consisting of at least seven or eight, all with axes nearly N.–S., with the exception of the one to the extreme east, which are so closely crowded together as to form along their bases one continuous mass. Double or twin hills are quite common, but this is the only case yet seen where more than two are thus united. This series, it should have been mentioned, is in the town of Maynard. Just south of the Acton line, in the northeast corner of Stow, is Flagg Hill, which consists of two parallel drumlins, with longer axes nearly N.–S., which, though united, are separated nearly to their bases, and just south of the village of South Acton Faulkner's Hill is formed in the same manner, where the valley between is sufficiently deep for the passage of the

highway. Also north of the same village there is first a single hill which is not of large size, and just northeast of this another couple that are more closely united than those just mentioned. About halfway between South and West Acton, on the north side of the railroad, is a small drumlin, and then just beyond West Acton station, but in the village, is a large drumlin, with its axis N.–10–W. and its summit very slightly divided. Just south of this is a small drumlin, with its axis nearly E.–W.

These few drumlins just enumerated are all that occur in Acton, the whole northern and eastern portions of the town being free from them, with the exception of Strawberry Hill, in the northeast corner. In Maynard, besides those previously mentioned, there is one, not very large, near the southeast corner of the town.

In Sudbury, just southeast of the southeast corner of Maynard, is Cutting's Hill, a very typical drumlin with axis very much elongated somewhat to the west of north. Then east of, and close to the line of the Lowell and Framingham railroad, are the hills just north of the centre of the town, Plympton's Hill, the composite one south of Pantry Brook, and one on the boundary line between Sudbury and Concord. Farther to the eastward Round Hill, "rising from the Sudbury meadows," as described by Thoreau, is a drumlin nearly circular in plan.

In Concord there are three prominent drumlins. That known as Annursnack, north of Concord Junction, is of considerable size, with axis slightly west of north. The maps of the United States Geological Survey give the height of this hill as 390 feet above sea-level. Just northwest of Concord Centre is a nearly circular drumlin, on which is situated the reservoir that supplies the town with water. Punkatasset Hill, northwest of the river road to Carlisle, is the third. This is well wooded and has not been very well examined. In Lincoln the only drumlin so far examined is a small one just south of the centre.

In Weston none whatever have so far been noted, though more than one-half its area has been investigated.

The sand plains of the modified drift have not received particular attention, and here it will only be noted that the prominent ones occupying this region are two in number, — the one surrounding Walden Pond in Concord, and the one known as Boon's Plain in Stow and Peakham Plain in Sudbury.

The kames have proved a very interesting feature and have received much attention.

One series traced northward from the farthest southern point known starts just north of Boon's Pond, Stow, passes along the northern end of

Boon's Hill, and disappears below the Assabet River. Rising again on the north bank of the river, it winds along the extreme eastern edge of the base of Priest's Hill, sometimes in a single ridge, sometimes in a series, and often giving off lateral branches of a few rods in length. Northeast of Priest's Hill it is covered for some distance by a small sand plain, but not to sufficient depth to prevent its being traced. In the vicinity of Stow Centre it is broken up into a tumultuous series of small hillocks, though in some parts keeping its correct form; continuing northward, it has been traced a short distance north of the Acton line. About a mile west of this, in the central part of Stow, is another short series, connected with this by a single lateral offshoot continuing for about a mile in a slightly northeast direction. Then this series seems to be continued in two short pieces in the southwest part of Acton, one extending a short distance on each side of the boundary line between Stow and Acton, and the other consisting of several parallel but short ridges near the Boxboro' boundary on the road from West Acton. Another series starts in the extreme northeast corner of Sudbury, and runs a well-defined single ridge for about a mile, when it disappears below a sand plain just at the Concord line, to emerge again as three parallel ridges on the banks of the Assabet just east of the powder mills. Then continuing as a single ridge most of the way, it is easily traced across the Fitchburg railroad in Acton nearly to the extreme northern point of the town, passing along the eastern slope of the high rocky eminence upon which Acton Centre stands. Directly in the correct range southward of the starting-point of this series in Sudbury, at intervals of a mile or so, there are indications that it may extend much farther than it has been traced, but covered from view by the sand plains which abound there. In Concord, running first along the eastern base of Annursnack Hill, and extending to nearly the northwest angle of the town, along the west bank of Spencer Brook, is a well-defined series mostly made up of a single ridge, but at the southern extremity broken into several nearly parallel ridges.

On the road leading directly north from Concord Centre toward Carlisle a single ridge has been traced for about a mile; but as this region is densely wooded, it is not known how much farther this series extends.

In Weston, on the west bank of Stony Brook, beginning about opposite the Kendall Green Station on the Fitchburg railroad, a well-defined kame runs along between the brook and the hill, where for a portion of the distance material has silted in behind the kame till it has produced a level surface from the top of the kame back to the hillside, giving

very strongly the appearance of a terrace. This series continues for some distance northward, crossing the railroad, passing to the north of Lincoln station, and continuing to the sand plain that surrounds Walden Pond.

This in brief gives a hasty summary of the facts brought to light so far in the study of the drift of this very interesting region. No theories or conclusions will be here advanced. They will be left for another paper, to be written after the conclusion of the work of the coming summer.

THE NUMBERS OF BACTERIA IN CERTAIN CITY TAP-WATERS.

BY EDWIN O. JORDAN.

IN the spring of 1888, as an incidental study, a bacteriological examination was made of the tap-waters of Newton, Cambridge, Boston (Cochituate), and Charlestown (Mystic), Mass. All the work was done between March 20 and May 13. The samples of water were taken in sterilized bottles, brought at once to the Biological Laboratory and planted within three hours from the time of collection. From the statistics of the Massachusetts State Board of Health I have obtained also the analyses of the tap-water of Lawrence, Mass., made during the same time. Through the courtesy of Mr. Schultz, of the Boston Signal Service Station, the mean daily temperature and the total precipitation in inches and hundredths of inches as recorded at the station have been tabulated for all the dates on which samples of water were examined. The dates, on the whole, fail to show any very decided relation between the numbers of bacteria in the water and the general atmospheric conditions.

It should be remembered that the sources of supply of the several places are widely separated and that the Boston records give only an approximate indication of the precipitation, etc., at the various reservoirs and ponds. Nevertheless, some general conclusion as to the effect of rainfall appear to be warranted.

The two extreme samples of each supply were those taken on the following days: —

Newton	May 7,	52	May 1,	0
	May 3,	44	April 28,	2
Cambridge	May 11,	1188	April 23,	22
	April 7,	644	April 24,	22
Boston	April 7,	1684	May 1,	12
	April 19,	592	April 28,	22
Charlestown	March 31,	1318	April 30,	60
	April 14,	1186	April 27,	76
Lawrence	March 24,	206	April 28,	24
	March 31,	184	May 10,	33

The high numbers are distributed quite evenly over the whole period, but the low numbers are crowded together into about ten days in the last part of April. On referring to the table it is seen that between April 22 and May 1 no rain fell. It was the longest "dry spell" during the time of investigation. This connection of low numbers of bacteria with absence of rainfall suggests more than a mere coincidence. In several instances the high numbers of bacteria follow closely upon a heavy rainfall. That such is not invariably the case is not remarkable, for the local conditions and irregularities in distribution would account in part at least for the discrepancies observed. Changes of the temperature of the air, accompanying the change of season, have evidently little or no effect upon the number of bacteria. The results seem to indicate that the main agent in raising the count of bacteria is the amount of precipitation. It is not probable that this increase comes directly from bacteria in the rain-water or from those caught on its way through the air, but that it comes largely from those washed out of the soil. The upper layers of earth are known to be abundantly filled with bacteria, and a pelting rain that furrows every hillside must undoubtedly wash into the ponds and reservoirs immense numbers of these surface bacteria, and also considerable food material. In ordinary wells communicating more or less freely with the surface the water is found decidedly richer in bacteria after a rain-storm. The work of Dr. Theobald Smith * points in the same direction. He concludes from his work on the Potomac water that the high numbers of bacteria in that water in winter come directly from the soil. The condition of the surface soil in winter, in his opinion, lets the earth wash into the river more easily than in summer, when it is bound together with vegetation and protected by overhanging trees. I have not been able to trace in this locality any such relation between the time of year and the number of bacteria in the water. The effect of rainfall, however, in a general way appears to be considerable, and is dependent on varying local conditions, rather than on any general climatic changes.

That the banks of reservoirs, filter-basins, etc., are often richly manured is of a certain interesting significance for us.

* Medical News, April 9, 1887.

1888.	Newton.	Boston.	Cambridge.	Charlestown.	Lawrence.	Mean Daily Temp.	Rainfall in inches.*
March 20 . .	10	156	—	—	107	46.7	.03 .73
" 22 . .	4	112	—	—	68	37.3	.06
" 23 . .	6	208	—	—	—	20.0	—
" 24 . .	22	152	—	—	206	19.0	—
" 26 . .	20	230	—	—	—	31.3	.23
" 27 . .	10	—	—	—	99	37.0	.43
" 28 . .	6	138	—	—	—	41.7	.32
" 29 . .	14	84	44	192	141	41.7	.20
" 30 . .	10	—	224	—	—	41.7	—
" 31 . .	4	62	278	1318	184	42.7	—
April 2 . .	12	416	32	254	—	38.3	.02 .58
" 4 . .	26	238	168	154	98	40.3	—
" 6 . .	10	106	82	458	—	47.3	.40 .26
" 7 . .	24	1684	240	460	—	39.3	—
" 9 . .	30	54	64	156	—	35.7	—
" 10 . .	28	226	54	116	—	35.3	.11
" 11 . .	20	222	306	106	—	40.0	.29
" 12 . .	12	36	—	432	—	43.3	.01
" 13 . .	16	236	134	296	—	37.3	—
" 14 . .	12	360	—	1186	—	38.3	.11
" 16 . .	16	210	26	310	—	40.7	.09 .01
" 17 . .	8	160	58	228	—	43.0	—
" 18 . .	14	122	32	344	—	44.0	.05
" 19 . .	26	592	—	203	—	48.0	—
" 21 . .	—	—	76	274	—	40.7	.06 .05
" 23 . .	4	118	22	162	—	42.0	Tr.
" 24 . .	6	118	22	262	—	39.7	—
" 25 . .	4	126	—	212	—	40.3	—
" 26 . .	10	84	30	296	—	53.0	—
" 27 . .	12	30	36	76	—	50.3	—
" 28 . .	2	22	34	128	24	56.0	—
" 30 . .	6	24	40	60	—	43.7	—
May 1 . .	0	12	90	—	—	41.7	.03 .03
" 3 . .	44	124	212	122	—	45.3	—
" 7 . .	52	58	644	546	—	57.0	—
" 8 . .	12	90	182	272	40	56.3	Tr.
" 9 . .	24	66	82	148	—	56.3	.53
" 10 . .	12	26	—	124	33	62.3	.01
" 11 . .	18	144	1100	146	—	45.7	.38
" 12 . .	16	142	308	124	128	52.7	1.42

Newton	Average of 39 analyses		15
Boston	" " 37 "		189
Cambridge . . .	" " 28 "		201
Charlestown . . .	" " 31 "		295
Lawrence	" " 11 "		103

* Boston Signal Service Station.

*REFRIGERATING MACHINES.**

By C. H. PEABODY, S.B.

In the discussion of heat engines it appears that the simplest cycle described by such an engine is that for Carnot's ideal engine represented by Fig. 1.

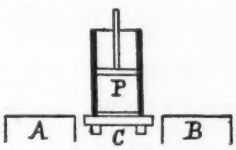

Fig. 1.

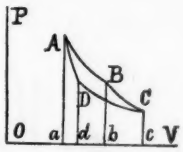

Fig. 2.

When the working substance in the cylinder P is a gas, the cycle represented by Fig. 2 is composed of two isothermal lines, AB and CD, and of two adiabatic lines, BC and DA. When the working substance is a mixture of a liquid and its vapor, the two isothermal lines become parallel to the axis OV, but the order of events is in nowise altered.

When working direct, Carnot's engine takes from the source of heat A a quantity of heat Q, changes a part into mechanical energy, rejects the remainder Q_1, to the refrigerator B. The efficiency

$$\eta = \frac{AW}{Q} = \frac{Q - Q_1}{Q} = \frac{T - T_1}{T_1}$$

increases with the difference of temperatures of the source of heat and the refrigerator.

If the engine be reversed so that it describes the cycle in the order $ADCBA$, it takes heat from the refrigerator, adds thereto the heat equivalent of the work of the cycle, and delivers the sum to the source of heat, and thus becomes a refrigerating machine. It is apparent that in this action it is desirable to do as little work as possible on the working substance, and that this condition is fulfilled by making the difference of temperatures as small as possible.

In practice, it is found convenient to supply to a heat engine at each stroke a quantity of the working substance at a high temperature,

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which does work on the piston and is rejected at a lower temperature. Thus the steam engine takes steam from the boiler which serves as a source of heat, and after abstracting some of the heat in the form of work, rejects the steam to the condenser or refrigerator. In like manner refrigerating machines take a supply of the working substance from the refrigerator or refrigerant, do work upon it, and deliver it at a higher temperature to a receptacle which is known as the cooler or condenser, but which takes the place of the source of heat or boiler.

Two forms of refrigerating machines are in common use, air refrigerating machines, and compression refrigerating machines using a saturated vapor, such as the ammonia refrigerating or ice machine.

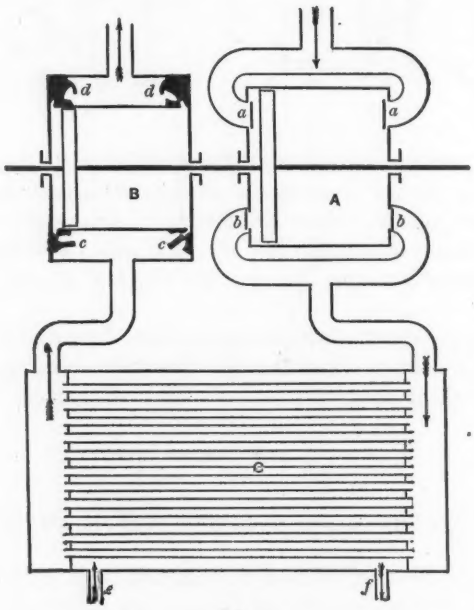


FIG. 3.

Air Refrigerating Machine. — The general arrangement of an air refrigerating machine is shown by Fig. 3.

It consists of a compression cylinder *A*, an expansion cylinder *B* of smaller size, and a cooler *C*. It is commonly used to keep the atmosphere in a cold storage room at a low temperature, and has certain advantages for this purpose especially on shipboard. The air from the storage room comes to the compression at or about freezing point, is

compressed to two or three atmospheres, and delivered to the cooler, which has the same form as a surface condenser, with cooling water entering at *e* and leaving at *f*. From the cooler the air, usually somewhat warmer than the atmosphere, goes to the expansion cylinder *B*, in which it is expanded nearly to the pressure of the air and cooled to a low temperature, and then delivered to the storage room. The inlet valves *a*, *a*, and the delivery valves *b*, *b*, of the compressor, are moved by the air itself; the admission valves *c*, *c*, and the exhaust valves *d*, *d*, of the expansion cylinder, are like those of a steam engine, and must be moved by the machine. The difference between the work done on the air in the compressor, and that done by the air in the expansion cylinder, together with the friction work of the whole machine, must be supplied by a steam engine or other motor.

The effect of clearance in the compression cylinder is to increase the size required for a certain performance. The exhaust valves of the expansion cylinder should be so set that the clearance shall be filled by compression with air at nearly, if not quite the admission pressure, and the cut-off should be such that the air shall expand down to the back pressure.

This latter is always of importance for the efficient action of the machine; but if the clearance is small, the compression is of less moment.

It is customary to provide the compression cylinder with a water jacket to prevent overheating, and frequently a spray of water is thrown into the cylinder to reduce the heating and the work of compression. Sometimes the cooler *C*, Fig. 3, is replaced by an apparatus resembling a steam-engine jet condenser, in which the air is cooled by a spray of water. In any case it is essential that the moisture in the air as well as in the water injected should be efficiently removed before the air is delivered to the expansion cylinder, otherwise snow will form in that cylinder and interfere with the action of the machine. Various mechanical devices have been used to collect and remove water from the air, but air may be saturated with moisture after it has passed such a device.

The Bell-Coleman company use a jet cooler, with provision for collecting and withdrawing water, and then pass the air through pipes in the cold room on the way to the expansion cylinder. The cold room is maintained at a temperature a little above freezing point, so that the moisture in the air is condensed upon the sides of the pipes and drains back into the cooler. The same machine as made by Menck and Hambrock, is provided with a device for removing moisture from the air, that is shown by Fig. 4. Air from the cooler comes in by the pipe *a*, is distributed by the annular perforated pipe *b*, and passes out to the ex-

pansion cylinder by the pipe *c*. The chamber *E* is surrounded by a jacket, through which passes the cold air on the way from the expansion cylinder to the cold room. Since the air in the jacket is many degrees below freezing point, walls of the chamber *E* are quickly covered with frost, which accumulated till a considerable thickness is attained; afterwards, the moisture condenses and runs down to the bottom of the chamber, from whence it is withdrawn.

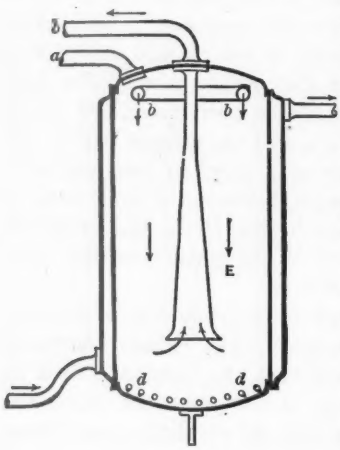


FIG. 4.

A coil of steam pipe *d*, *d* is provided for thawing ice and snow that may accumulate at the bottom of the chamber. Since the same air is used continuously, being taken from the cold room, chilled, and returned, the effect of these devices is to remove the moisture from the air in the cold room, and to maintain a cold, dry atmosphere in it, which is well adapted to preserving all kinds of perishable provisions.

When an air refrigerating machine is used as described, the pressure in the cold room is necessarily that of the atmosphere, and the size of the machine is large as compared with its performance. The performance may be increased by running the machine on a closed cycle with higher pressure; for example, cold air may be delivered to a coil of pipe in a non-freezing salt solution, from which the air abstracts heat through the walls of the pipe and then passes to the compressor to be used over again. The machine may then be used to produce ice, or the brine may be used for cooling spaces or liquids. A machine has been used for producing ice on a small scale without cooling water on the reverse of this principle; that is, atmospheric air is first expanded and chilled and delivered to a coil of pipe in a salt solution, then the air is drawn from this coil, after absorbing heat from the brine, compressed to atmospheric pressure and expelled.

Calculation of Air Refrigerating Machine. — The performance of a refrigerating machine may be stated in terms of the number of thermal units withdrawn in a unit of time, or in terms of weight of ice produced. The latent heat of fusion of ice may be taken to be 80 calories, or 744 B.T.U.

Let the pressure at which the air enters the compression cylinder be

p_1, that at which it leaves be p_2; let the pressure at cut-off in the expanding cylinder be p_3, and that of back pressure in the same be p_4; let the temperatures corresponding to these pressures be t_1, t_2, t_3, and t_4, or record from the absolute zero, T_1, T_2, T_3, and T_4. With proper valve gear and large, short pipes communicating with the cold chamber, p_4 may be assumed to be equal to p_1, and equal to the pressure in that chamber. Also t_1 may be assumed to be the temperature maintained in the cold chamber, and t_3 may be taken to be the temperature of the air leaving the cooler. With a good cut-off mechanism and large passages p_3 may be assumed to be nearly the same as that of the air supplied to the expanding cylinder. Owing to the resistance to the passage of the air through the cooler and the converting pipes and passages, p_3 is considerably less than p_2.

The expansion in the expanding cylinder may be assumed to be adiabatic, so that

$$\frac{T_4}{T_3}=\left(\frac{p_4}{p_3}\right)^{\frac{\kappa-1}{\kappa}}.$$

Were the compression also adiabatic, the temperature t_2 could be determined in a similar manner; but the air is usually cooled during compression, and contains more or less vapor, so that the temperature at the end of compression cannot be determined from the pressure alone, even though the equation of the expansion curve be known.

Let the air passing through the refrigerating machine per minute be M; then the heat withdrawn from the cold room is

$$Q_1=Mc_p(t_1-t_4). \tag{1}$$

The work of compressing M units of weight of air from the pressure p_1 to the pressure p_2 in a compressor without clearance is

$$W_c=M\left\{p_1v_1+\int_{v}^{v_1}pdv-p_2v_2\right\}=Mp_1v_1\frac{n}{n-1}\left\{\left(\frac{p_2}{p_1}\right)^{\frac{n-1}{n}}-1\right\} \tag{2}$$

provided that the compression curve can be represented by an exponential equation.

The work will be the same for a compressor with clearance if the exponent for the equation to the expansion curve is the same as that for the compression curve. If the compression can be assumed to be adiabatic,

$$W_c=Mp_1v_1\frac{\kappa}{\kappa-1}\left\{\left(\frac{p_2}{p_1}\right)^{\frac{\kappa-1}{\kappa}}-1\right\}=\frac{Mc_p}{A}(t_2-t_1); \tag{3}$$

for in such case we have the equation

$$\frac{T_2}{T_1}=\left(\frac{p_2}{p_1}\right)^{\frac{\kappa-1}{\kappa}}, \qquad AR=c_p-c_v=c_p\frac{\kappa-1}{\kappa}.$$

The work done by the air in the expanding cylinder should be calculated in the manner used in designing a steam engine. If the expansion and compression are both complete, then the work done by M units of weight of air is

$$W_e=\frac{Mc_p}{A}(t_3-t_4). \tag{4}$$

The work that must be supplied per minute is

$$W=W_c-W_e,$$

and the net horse-power required is

$$\frac{W}{33000}\text{H.P};$$

but the gross horse-power required is much larger, since all the frictional resistances must be overcome, including the friction of both pistons.

The proper allowance can readily be determined on a machine with a steam engine coupled direct, by indicating both of the air cylinders and the steam cylinder simultaneously. The heat carried away by the cooling water is

$$Q=Q_1+AW. \tag{5}$$

If compression and expansion are both adiabatic, then

$$Q=Mc_p(t_1-t_4+t_2-t_1-t_3+t_4)=Mc_p(t_2-t_3). \tag{6}$$

If the initial and final temperatures of the cooling water are t_i and t_k, and if q_i and q_k are the corresponding heats of the liquid, then the weight of cooling water per minute is

$$G=\frac{Q}{q_k-q_i}.$$

A good supply of cooling water and a method of regulating it, should be provided; so that an approximate calculation may be made for every case, under the assumption of adiabatic compression and expansion by the equation

$$G=\frac{Mc_p(t_2-t_3)}{q_k-q_i}. \tag{7}$$

The volume of compression piston displacement regulating clearance is

$$V_c = \frac{Mv_1}{2n} = \frac{Mp_0 T_1}{2np_1 T_0} v_0 = \frac{MRT_1}{2np_1}, \tag{8}$$

in which n is the number of revolutions per minute, and p_0, v_0, T_0 are the pressure volumes and absolute temperature at atmospheric pressure and at freezing point.

If it be assumed that p_4 is the same as p_1, then the volume of the expanding cylinder without clearance may be assumed to be

$$V_e = V_c \frac{T_4}{T_1}. \tag{9}$$

If the clearance of the compressor is $\frac{1}{m}$ of the piston displacement, then the volume of air in the cylinder when the inlet valve opens is

$$\frac{1}{m}\left(\frac{p_2}{p_1}\right)^{\frac{1}{n}},$$

and the volume calculated by equation (8) should be multiplied by

$$1 + \frac{1}{m}\left(\frac{p_2}{p_1}\right)^{\frac{1}{n}} - \frac{1}{m}.$$

If the expansion and compression in the expanding cylinder are complete, the same expansion may be used to allow for clearance in that cylinder, making n equal to κ.

To allow for loss of pressure in valves and passage and for other imperfections, both of these volumes may be increased by an amount to be determined by experiment.

In practice, the expansion is seldom carried down to the back pressure in the expanding cylinder, nor is the compression complete, and the volume is smaller than that given by equation (9).

The temperature T_4 may be controlled by the cut-off of the expanding cylinder, and thus the performance of the machine may be varied.

As the cut-off is shortened, p_2 is increased and T is diminished, and this in turn makes V_e smaller compared with V_c.

Problem. — Required the dimensions of an air refrigerating machine to produce an effect equal to the melting of 200 pounds of ice per hour. Let the pressure in the cold chamber be 14.7 pounds, and the temperature 32° *F.* Let the pressure at cut-off in the expanding cylinder be 29.4 pounds by the indicator, or 44.1 pounds absolute. Let the delivery pressure in the compressor be 39.4 pounds by the indicator, *i.e.* let the

loss of pressure in the cooler and passages be 10 pounds. Let the initial and final temperatures of the cooling water be 60° and 80° F., and the temperature of the air from the cooler, 90° F.

Let the machine make 60 revolutions per minute.

The melting of 200 pounds of ice per hour is equivalent to 28,800 B.T.U. per hour, or 480 B.T.U. per minute.

Assuming adiabatic compression and expansion

$$T_4 = 492.7\left(\frac{14.7}{44.1}\right)^{\frac{0.4}{1.4}} = 360\,; \quad \therefore t_4 = -100.°7 \text{ F.}$$

$$T_2 = 492.7\left(\frac{54.1}{14.7}\right)^{\frac{0.4}{1.4}} = 714.9\,; \quad \therefore t_2 = 254.°2 \text{ F.}$$

The air used per minute is therefore

$$480 \div (32 + 100.7) \times 0.2375 = 12.10 \text{ pounds.}$$

The horse-power of the compression cylinder with an adiabatic compression is

$$\frac{W_c}{33000} = \frac{12.1 \times 778 \times 0.2375 \times (254.2 - 32)}{33000} = 15.0 \text{ H.P.}$$

If the compression curve may be represented by

$$pv^{1.2} = \text{const.},$$

then the work of compression will be

$$W_c = 12.1 \times 144 \times 14.7 \times 12.4 \times \frac{1.2}{0.2}\left\{\left(\frac{54.1}{14.7}\right)^{\frac{0.2}{1.2}} - 1\right\} = 49{,}230 \text{ foot-pounds,}$$

and the horse-power is therefore 14.0.

The horse-power of the expanding cylinder is

$$\frac{W_e}{33000} = \frac{12.1 \times 778 \times 0.2375 \times (32 + 100.7)}{33000} = 9.0 \text{ H.P.}$$

The net horse-power required is therefore 6 H.P. or 5 H.P., and the indicated horse-power of the steam cylinder may be assumed to be 8 H.P., or $6\frac{2}{3}$ H.P., according to the manner of the compression.

The volume of the compression piston displacement without clearance will be

$$\frac{12.1 \times 12.4}{120} = 1.25 \text{ cubic feet.}$$

The volume of the expanding cylinder under the same condition is

$$1.25 \times \frac{360}{492.7} = 0.91 \text{ cubic feet.}$$

If the clearance of the compressor be assumed to be 0.02, the piston displacement should be

$$1.25\left\{1+0.02\left(\frac{54.1}{14.7}\right)^{\frac{1}{1.2}}-0.02\right\}=1.4 \text{ cubic feet.}$$

If the clearance of the expanding cylinder be assumed to be 0.05, the piston displacement should be

$$0.91\left\{1+0.05\left(\frac{44.1}{14.7}\right)^{\frac{1}{1.4}}-0.05\right\}=0.96 \text{ cubic feet.}$$

If, further, an allowance of ten per cent be made for imperfections, the dimensions may be: diameter, compressor, 17 inches; diameter, expanding cylinder, 14 inches; stroke, 12 inches.

Compression Refrigerating Machine. — The arrangement of a refrigerating machine using a volatile liquid and its vapor is shown by Fig. 5.

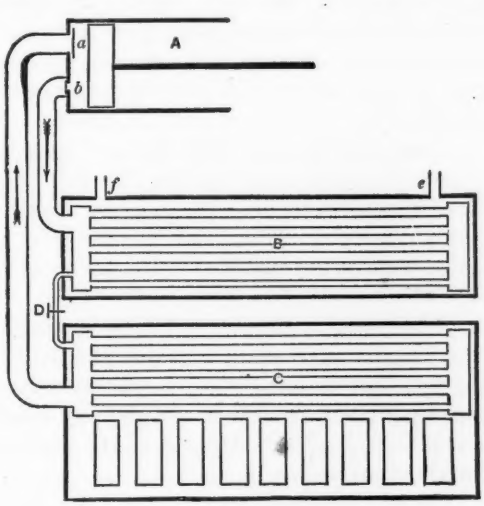


FIG. 5.

The essential parts are the compressor *A*, the condenser *B*, valve *D*, and the vaporizer *C*. The compressor draws in the vapor at a low pressure and temperature, compresses it and delivers it to the condenser, which consists of coils of pipe surrounded by cooling water that enters at *e* and leaves at *f*. The vapor is condensed, and the resulting liquid gathers in a reservoir in the bottom, from whence it is led by a small pipe having a regulating valve *D* to the vaporizer or refrigerator. The

refrigerator is also made up of coils of pipe, and is immersed in a non-freezing solution of salt, commonly chloride of calcium.

The volatile liquid vaporizes and withdraws heat from the surrounding brine, and reduces the temperature below freezing point of water. In the figure, the machine is represented to be applied to ice making, the water being introduced and frozen in properly shaped moulds of thin metal.

When the machine is used to cool a room, the vaporizer may be made up of a system of pipes arranged to withdraw heat from the air, or brine may be cooled and circulated through such a system of pipes. When brine is used, either in ice making or in cooling, a positive circulation should be given it by a pump or the equivalent.

In Fig. 5, the compressor is represented as single acting, but for horizontal machines it is commonly made double acting. Frequently the compressor has two single-acting vertical cylinders driven by a horizontal steam engine coupled to the shaft. Such compressors sometimes have the clearance filled with oil, of which part is forced through the delivery valves, and allowed to flow back into the cylinder during the inflow of vapor. In any case, it is of great importance that the clearance shall be reduced to the smallest amount possible. To make the cycle of the machine complete, the liquid from the condenser should be allowed to do work in an expansion cylinder like that of an air refrigerating machine, instead of flowing through the regulating valve *D*. The size of such a cylinder would be small, and the work recovered, insignificant, so that none of the machines in use are provided with such an expansion cylinder.

Calculation of Compression Machine. — Let the pressure in the condenser be p_1, the temperature t_1, and the heat of the liquid q_1. Let the pressure in the vaporizer or refrigerator be p_2, the temperature t_2, and the total heat of vaporization λ_2. The heat withdrawn from the refrigerant to change one unit of weight of liquid at the temperature t_1 into saturated vapor at the pressure p_2 is

$$\lambda_2 - q_1,$$

so that the heat withdrawn per minute by a machine using M units of weight of the working fluid per minute is

$$Q_1 = M(\lambda_2 - q_1). \qquad (10)$$

Even though the compressor cylinder be water-jacketed, the walls are at a considerably higher temperature than the entering vapor, and the pressure during admission is a little lower than that in the vapo-

rizer. Also, most of the vapors now used in such machines are superheated by adiabatic compression. Therefore it is probable that the vapor is superheated during compression, even though it be moist as it leaves the vaporizer. For an approximate calculation it may be assumed that the pressure in the cylinder during admission is p_2, that the vapor is dry and saturated at the beginning of compression, and that it is compressed adiabatically and superheated during the entire compression.

It will be shown that ammonia and sulphur dioxide, when moderately superheated, have the approximate characteristic equation

$$pv = BT - Cp^{\frac{\kappa-1}{\kappa}}, \tag{11}$$

and that during an adiabatic change we have the equation

$$\frac{T}{T_1} = \left(\frac{p}{p_1}\right)^{\frac{k-1}{k}}. \tag{12}$$

During the expulsion of vapor from the compressor, the pressure in the cylinder is a little higher than in the condenser, but it may be assumed to be the same for our approximate calculation. The temperature of the vapor leaving the compressor and entering the condenser may consequently be calculated by the equation

$$\frac{T_s}{T_2} = \left(\frac{p_1}{p_2}\right)^{\frac{\kappa-1}{\kappa}}. \tag{13}$$

The heat that must be withdrawn by the cooling water is, therefore,

$$Q = M\{c_p(t_s - t_1) + r_1\}, \tag{14}$$

in which c_p is the specific heat of the superheated vapor, at constant pressure, and r_1 is the heat of vaporization at the pressure p_1.

If the initial and final temperature of cooling water are t_i and t_k, and if q_i and q_k are the corresponding heats of the liquid for water, then the weight of cooling water used per minute is

$$G = \frac{Mc_p(t_s - t_1) + r_1}{q_k - q_i}. \tag{15}$$

For the first approximation, the horse-power of the compressor may be calculated by the expression

$$\frac{778 \times M\{c_p(t_s - t_1) + \lambda_1 - \lambda_2\}}{33000}. \tag{16}$$

The power thus calculated should be multiplied by a factor to be found by experiment, in order to find the probable indicated horse-power of the compressor, and the indicated horse-power must be multiplied by another factor to find the power required to drive the machine, or by a factor to find the indicated horse-power of a steam engine coupled to the shaft driving the compressor. If the actual pressure in the cylinder of the compressor during admission and delivery are p'' and p', if the specific volume at the beginning of compression is v'', and if the compression and expansion curves may be represented by the equation

$$pv^n,$$

then the horse-power of the compressor may be found by the expression

$$\frac{Mp''v''}{33000} \cdot \frac{n}{n-1} \left\{ \left(\frac{p'}{p''} \right)^{\frac{n-1}{n}} - 1 \right\}. \tag{17}$$

If the vapor at the beginning of compression can be assumed to be dry and saturated, then the volume of the piston displacement of a compressor without clearance, and making N strokes per minute, is

$$V = \frac{Mv_2}{N}. \tag{18}$$

To allow for clearance, the volume thus found may be multiplied by the factor

$$1 + \frac{1}{m} \left(\frac{p_1}{p_2} \right)^{\frac{1}{n}} - \frac{1}{m}, \tag{19}$$

in which $\frac{1}{m}$ is the clearance expressed as a fraction of the piston displacement. The volume thus found is further to be multiplied by a factor to allow for inaccuracies and imperfections. The vapors used in the compression machines are liable to be mingled with air or moisture, and in such case the performance of the machine is impaired. To allow for such action, the size and power of the machine must be increased practice above those given by calculation. It would appear that proper precautions ought to be taken to prevent such action from becoming of importance.

Problem. — Required the dimensions of an ammonia refrigerating machine to produce 2000 pounds of ice per hour. Let the temperature of the salt solution be 14° F., and the temperature in the condenser 86° F.; let the initial and final temperatures of the cooling water be 60° and 80° F. Let the compressor be double acting, and let it make 60 revo-

lutions per minute. The pressures corresponding to the temperatures 14° and 86° are 41.5 and 168.2 pounds, absolute, per square inch; or 26.8 and 153.8 pounds by the gauge. For ammonia $k = \frac{4}{3}$ mm. by equation (13)

$$T_s = (14 + 460.7)\left(\frac{168.2}{41.5}\right)^{\frac{1}{4}} = 673.7;$$

$$t_s = 213° \text{ F.}$$

If 5 per cent be allowed for ice wasted in removing it from the moulds, and for other losses, the capacity of the machine per minute must be

$$\frac{2100 \times 144}{60} = 5040 \text{ B.T.U.}$$

$$\therefore Q_1 = 5040 = M(\lambda_2 - q_1) = M(554 - 59).$$

$$\therefore M = \frac{5040}{495} = 10.2 \text{ pounds.}$$

The heat withdrawn by the cooling water is

$$Q = M\{c_p(t_s - t_1) + r_1\};$$

$$Q = 10.2\{0.508(213 - 86) + 497\} = 5727 \text{ B.T.U.}$$

The cooling water required per minute is consequently

$$G = \frac{5727}{q_2 - q_1} = \frac{5727}{48.09 - 28.12} = 287 \text{ pounds.}$$

The horse-power will be, approximately,

$$\frac{778\, M\{c_p(t_s - t_1) + \lambda_1 - \lambda_2\}}{33000} = \frac{778 \times 10.2\{0.508(213 - 86) + 556 - 297\}}{33000} = 77.8.$$

The horse-power of the steam cylinder may be assumed to be

$$77.8 \div 0.80 = 97.2.$$

On the assumption that the vapor in the compressor is dry and saturated at the beginning of compression, the volume of the piston displacement, not allowing for clearance, is

$$V = \frac{Mv_2}{N} = \frac{10.2 \times 7.05}{2 \times 60} = 5.15 \text{ cubic feet.}$$

If we allow 10 per cent for the effect of clearance and imperfect action, then the volume should be 5.7 cubic feet, or about 20½ inches in diameter by 30 inches, stroke.

Fluids Available. — The fluids that have been used in compression refrigerating machines are ether, sulphurous acid, ammonia, and a mixture of sulphurous acid and carbonic acid, known as Pictet's fluid.

The pressures of the vapors of these fluids at several temperatures, and also the pressures of the vapors methylicether and carbonic acid are given in the following table: —.

PRESSURES OF VAPORS (mm. of Mercury).

Temperatures. Degrees-centigrade.	Ether.	Sulphur dioxide.	Methylether.	Ammonia.	Carbon dioxide.	Pictet's fluid.
−30	—	287.5	576.5	866.1	—	585
−20	68.9	479.5	882.0	1392.1	15142	745
−10	114.7	762.5	1306.6	2144.6	20340	1018
0	184.4	1165.1	1879.0	3183.3	26907	1391
10	286.8	1719.6	2629.0	4574.0	34999	1938
20	432.8	2462.1	3586.0	6387.8	44717	2584
30	634.8	3431.8	4778.0	8701.0	56119	3382
40	907.0	4670.2	—	11595.3	69184	4347

Ether was used in the early compression machines, but at the temperatures maintained in the refrigerator, the pressure is small and the specific volume large, so that the machines were either feeble or bulky. Moreover air was liable to leak into the machine and unduly heat the compressor cylinder. Sulphurous dioxide has been used successfully, but it has the disadvantage that sulphuric acid may be formed by the leakage of moisture into the machine, in which case rapid corrosion occurs. Ammonia has been extensively used in the more recent machines with good results. When distilled from an aqueous solution it is liable to contain considerable moisture. As is shown by the table, Pictet's fluid has a pressure at low temperatures intermediate between the pressures of sulphuric dioxide and ammonia, and the pressure increases slowly with the temperature.

The properties of saturated vapor of ether were determined by Regnault. For the other vapors given in the table (except Pictet's fluid), he determined the relations of the temperature and pressure, but not the total heat of refrigeration nor the heat of the liquid. He did, however, determine some of the properties of these substances in the gaseous state, or more properly, in the state of superheated vapors.

It was first proposed by Ledoux* that the properties of superheated vapors of sulphur dioxide and ammonia can be represented by equations of the form deduced by Zenner for superheated steam, and that the application of those equations to the saturated vapors as the limit, makes it possible to calculate the properties of the saturated vapors approximately. His equations do not represent all the properties of the saturated vapors given by Regnault; consequently new equations have been calculated for both French and English units.

Properties of Sulphur Dioxide. — The specific heat of gaseous sulphur dioxide is given by Regnault† as 0.15438, and the coefficient of dilatation as 0.0039028. The theoretical specific gravity compared with air, calculated from the chemical composition, is given by Landolt and Börnstein‡ as 2.21295. Gmelin§ gives the following experimental determination, by Thomson, 2.222; by Berzilius, 2.247. The figure 2.23 will be assumed in this work, which gives for the specific volume at freezing point and at atmospheric pressure

$$v_0 = \frac{0.7735327}{2.23} = 0.347$$

cubic meters. The corresponding pressure and temperature are 10,333, and 273°.7 C. Now the coefficient of dilatation is the ratio of the increase of volume at constant pressure for one degree of increase of temperature, to the original volume. The general equation for a superheated vapor may be written

$$pv = \frac{c_p}{A} aT - Cp^n; \qquad (20)$$

consequently we have 0° C. and 1° C.

$$p_0 v_0 = \frac{c_p}{A} aT_0 - Cp_0^n,$$

$$p_0 v_1 = \frac{c_p}{A} aT_1 - Cp_0^n;$$

$$\therefore \frac{v_1 - v_0}{v_0} = \frac{c_p}{A} \cdot \frac{a}{p_0 v_0}.$$

Substituting the known values and solving for a, we obtain 0.212; but the results obtained from the equation (20) with this figure does not agree well with Regnault's experiments on the compressibility of sulphur dioxide.

* Annals de Mines, 1878. † Memoirs de la Institut de France, Tome xxi., xxvi.
‡ Physikalische-chemische Tabellen. § Watt's translation, p. 280.

If, instead, we make

$$a = 0.22,$$

then by equation (20) the coefficient of dilatation becomes 0.00404, and it will be shown later that the equation deduced with this volume agrees quite well with the experiments on compressibility.

The coefficient of T in equation (20) is therefore

$$0.15438 \times 426.9 \times 0.22 = 14.5,$$

and the coefficient of p^a is

$$\frac{14.5 \times 273.7 - 10333 \times 0.347}{10333^{0.22}} = 48 \text{ nearly},$$

so that the equation becomes

$$pv = 14.5\, T - 48\, p^{0.22}. \qquad (21)$$

Regnault found for the pressures

$$p_1 = 697.83 \text{ mm. of mercury},$$

$$p_2 = 1341.58 \text{ mm. of mercury},$$

and at 7.°7 C., the ratio

$$\frac{p_1 v_1}{p_2 v_2} = 1.02088.$$

Reducing the given pressures to kilogrammes on the square inch and the temperatures to the absolute scale, and applying to equation (20), we obtain instead of the experimental value for the above ratio 1.016.

Regnault gives for the pressure of saturated sulphur dioxide, in mm. of mercury, the equation

$$\log p = a - b\alpha^n - c\beta^n;$$

$$a = 5.6663790;$$

$$\log b = 0.4792425;$$

$$\log c = 9.1659562 - 10;$$

$$\log \alpha = 9.9972989 - 10;$$

$$\log \beta = 9.98729002 - 10;$$

$$n = t + 28° \text{ C.}$$

The differential coefficient may be calculated by the following equation:—

$$\frac{1}{p}\frac{dt}{dt} = A\alpha^n + B\beta^n;$$

$$\log \alpha = 9.9972989;$$

$$\log \beta = 9.98729002;$$

$$\log A = 8.6352146;$$

$$\log B = 7.9945332;$$

$$n = t + 28^\circ \text{ C.}$$

The specific volume of saturated sulphur dioxide may be calculated by inserting in equation (21) for the superheated vapor, the pressures calculated by aid of the equation at the bottom of page 340. The results at several temperatures are as follows:—

t	-30° C.	0	$+30^\circ$ C.
S	0.8292	0.2256	0.0825

Andréeff * gives for the specific gravity of fluid sulphur dioxide 1.4336. Consequently the specific volume of the liquid is

$$\sigma = 0.0007.$$

The value of r, the heat of vaporization, may now be calculated at the given temperatures by equation (22).

$$r = AuT\frac{dp}{dt}, \qquad (22)$$

in which

$$u = s - \sigma.$$

The results are

t	-30° C.	0	$+30^\circ$ C.
r	106.9	97.60	90.54

Within the limits of error of our method of calculation the value of r may be found by the equation

$$r = 98 - 0.27\,t.$$

To find the specific heat of the liquid, we may use equation (23) †, obtained by equating expressions for the differential coefficient of the entropy of saturated steam and superheated steam.

$$Cp\left(1 - a\frac{T}{p}\cdot\frac{dp}{dt}\right) = C + \frac{dr}{dt} - \frac{r}{T}. \qquad (23)$$

* Ann. Chem. Pharm., 1859. † Thermodynamics of the Steam Engine, p. 120.

At 0° C. the specific heat is approximately

$$C = 0.4.$$

In English units we have for superheated sulphur dioxide

$$pv = 26.4\,T - 184\,p^{0.22}; \tag{24}$$

the pressures being in pounds on the square foot, the volumes in cubic feet, and the temperatures in Fahrenheit degrees absolute.

For pressures in pounds on the square inch at temperatures in Fahrenheit scale

$$\log p = a - b\alpha^n - c\beta^n;$$

$$a = 3.9527847;$$

$$\log b = 0.4792425;$$

$$\log c = 9.1659562 - 10;$$

$$\log \alpha = 9.9984994 - 10;$$

$$\log \beta = 9.99293890 - 10;$$

$$n = t + 18°.4 \text{ F.}$$

For the heat of vaporization

$$r = 176 - 0.27(t - 32), \tag{25}$$

and for the specific heat of the liquid

$$c = 0.4.$$

Properties of Ammonia. — The specific heat of gaseous ammonia, determined by Regnault, is 0.50836. The theoretical specific gravity compound with air, calculated from the chemical composition, is given by Landolt and Börnstein as 0.58890. Gmelin gives the following experimental determinations, by Thomson, 0.5931; by Biot and Arago, 0.5967. For this work the figures 0.597 will be assumed, which gives for the specific volume at freezing point and at atmospheric pressure

$$v_0 = \frac{0.7735327}{0.597} = 1.30$$

cubic metres. The coefficient of dilatation has not been determined, and consequently cannot be used to determine the value of a in equation (20). It however appears that very consistent results are obtained, if a is assumed to be $\frac{1}{4}$, as for superheated steam. The coefficient of T then becomes

$$0.50836 \times 426.9 \times \tfrac{1}{4} = 54.3,$$

and the coefficient of $p^{\frac{1}{4}}$ is

$$\frac{54.3 \times 273.7 - 10333 \times 1.30}{.10333^{\frac{1}{4}}} = 142,$$

so that the equation becomes

$$pv = 54.3\,T - 142\,p^{\frac{1}{4}}. \qquad (26)$$

The coefficient of dilatation calculated by the same process as that used in determining a for sulphur dioxide, is 0.00404, which may be compared with that for sulphur dioxide.

Regnault found for the pressures

$$p_1 = 703.50 \text{ mm. of mercury,}$$
$$p_2 = 1435.3 \text{ mm. of mercury,}$$

and at 8°.1 C, the ratio

$$\frac{p_1 v_1}{p_2 v_2} = 1.0188,$$

while equation (26) gives under the same conditions 1.0200.

For saturated ammonia, Regnault gives the equation

$$\log p = a - b\alpha^n - c\beta^n.$$
$$a = 11.5043330;$$
$$\log b = 0.8721769;$$
$$\log c = 9.9777087 - 10;$$
$$\log \alpha = 9.9996014 - 10;$$
$$\log \beta = 9.9939729 - 10;$$
$$n = t + 22^\circ \text{C};$$

by aid of which the pressures in mm. of mercury may be calculated for temperatures on the centigrade scale. The differential coefficient may be calculated by aid of the equation

$$\frac{1}{p}\frac{dp}{dt} = A\alpha^n + B\beta^n.$$
$$\log A = 8.1635170 - 10:$$
$$\log B = 8.4822485 - 10;$$
$$\log \alpha = 9.9996014 - 10;$$
$$\log \beta = 9.9939729 - 10;$$
$$n = t + 22^\circ \text{C}.$$

The specific volumes of saturated ammonia calculated by equation (26) at several temperatures are

t	$-30°$ C.	$0°$	$+30°$ C.
s	0.9982	0.2961	0.1167

Andréeff gives for the specific gravity of liquid ammonia at 0° C., 0.6364, so that the specific volume of the liquid is

$$\sigma = 0.0016.$$

The values of r at the several given temperatures calculated by equation (26) are

	$-30°$ C.	0	$+30°$ C.
r	325.7	300.15	277.5

which may be represented by the equation

$$r = 300 - 0.8t. \tag{27}$$

The specific heat of the liquid calculated by aid of equation (180)* is

$$c = 1.1.$$

In English units the properties of superheated or gaseous ammonia may be represented by the equation

$$pv = 99T - 540p^{\frac{1}{3}}, \tag{28}$$

in which the pressures are taken in pounds on the square foot, and volumes in cubic feet, while T represents the absolute temperatures in Fahrenheit degrees.

The pressure in pounds in the square inch may be calculated by the equation

$$\log p = a - b\alpha^n - c\beta^n.$$

$$a = 9.7907380;$$

$$\log b = 0.8721769 - 10;$$

$$\log c = 9.9777087 - 10;$$

$$\log \alpha = 9.9997786 - 10;$$

$$\log \beta = 9.9966516 - 10;$$

$$n = t + 7°.6 \text{ F.}$$

The heat of vaporization may be calculated by the equation

$$r = 540 - 0.8(t - 32) \tag{29}$$

and the specific heat of the liquid is

$$c = 1.1.$$

* Thermodynamics of the Steam Engine.

Pictet's Fluid. — Attention has already been called to the mixture of sulphur dioxide, carbon dioxide, known as Pictet's fluid, which was adopted by Pictet for use in his refrigerating machines after an extended investigation.

The desirable properties are stated by him to be:—

1. The tension of the vapor should be greater than that of sulphur dioxide and less than that of ammonia. The boiling point under atmospheric pressure should be about − 20° C.

2. The tension of the vapor in the condenser at about + 30° C., should be between 7 and 8 atmospheres.

3. The fluid should be incombustible.

4. The fluid should not attack metals.

5. The fluid should have such a chemical composition that changes of volatility during use need not be feared.

6. The fluid should be of an unctious nature, so that oil need not be used on the piston of the compressor.

7. The fluid should be inexpensive.

An investigation of the properties of various fluids shows that the addition of oxygen to any compound, whether it entered in solution or into chemical combination, diminished the volatility. Thus carbon monoxide boils at − 140° C., while carbon dioxide boils at − 75° C.; sulphur dioxide boils at − 10° C. and anhydrous sulphurous acid boils at + 32° C., while the hydrate boils at + 326° C.

Other examples are given by Pictet, showing the same result. As a result of experiments on the mixture of sulphur dioxide and carbon dioxide, he gives the following table of boiling points. The formula expresses the proportion of the elements in the mixtures, but are not to be taken to represent chemical compounds.

	Boiling Point.		Boiling Point C.
$C_{40}O_{82}S$	− 71°	CO_6S_2	− 15°
$C_{30}O_{62}S$	− 54°	CO_8S_3	− 12°
$C_{20}O_{42}S$	− 41°	$CO_{10}S_4$	− 9.°5
$C_{10}O_{22}S$	− 26°	$CO_{12}S_5$	− 8.°6
CO_4S	− 19°	$CO_{14}S_6$	− 8°
		$CO_{16}S_7$	− 7.°5

The mixture, which may properly be expressed by the formula $CO_2 + SO_2$, was found to fulfil all the seven desirable properties. And as is shown by the table on page (338), the pressure increases less rapidly with the temperature than for simple vapors; so that while the pressure at − 30° C. is double that of sulphur dioxide, the pressure at

+ 30° C. is a little less than that of that fluid. This remarkable property appears to be due to the increased solvent action of the two fluids on each other at higher pressures, which acts to diminish the mechanical work of compression from one temperature to another; for example, in the compressor of a refrigerating machine.

Absorption Refrigerating Apparatus. — Figure 6 gives an ideal diagram of a continuous absorption refrigerating apparatus. It consists of the following essential parts: (1), the generator *B* containing a concentrated solution of ammonia in water, from which the ammonia is driven

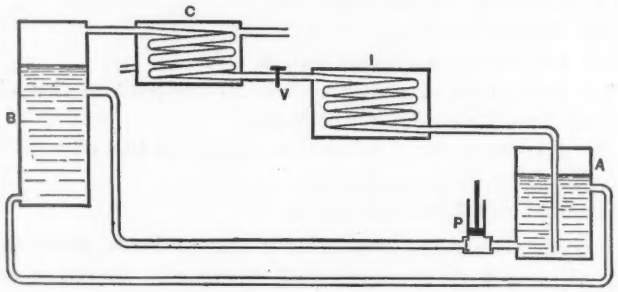


FIG. 6.

by heat; (2), the condenser *C*, consisting of a coil of pipe in a tank through which cold water is circulated; (3), the valve *V* for regulating the pressures in *C* and in *I*; (4), the refrigerator *I*, consisting of a coil of pipe in a tank containing a non-freezing salt solution; (5), the absorber *A*, containing a dilute solution of ammonia in which the vapor of ammonia is absorbed; and (6), the pump *P* for transferring the solution from the bottom of *A* to the top of *B*; there is also a pipe connecting the bottom of *B* with the top of *A*. It is apparent that the condenser and refrigerator or vaporizer correspond to the parts *B* and *C* of Fig. 5, and that the absorber and generator take the place of the compressor. The pipes connecting *A* and *B* are arranged to take the most concentrated solution from *A* to *B* and to return the solution from which the ammonia has been driven from *B* to *A*. In practice, the generator *B* is placed over a furnace, by which heat is applied to drive off the ammonia. Also, arrangements are made for transfering heat from the hot liquid flowing from *B* to *A*, to the cold liquid flowing from *A* to *B*. As the ammonia is distilled from water in *B* the vapor driven off contains some moisture, which causes an unavoidable loss of efficiency. The earliest absorption apparatus, made by Carre, consisted of a cylindrical receptacle containing a solution of ammonia, and acting alternately

as generator and absorber, in open communication through a pipe with a vessel of double conical form, acting alternately as condenser and refrigerator. In use, the generator was placed on a furnace, and the condenser in a tank of cold water, and the ammonia driven off from the solution condensed between the inner and outer conical surface of the condenser. When a sufficient amount of liquid ammonia had collected, the vessel containing the solution was transferred to the furnace to the cold water tank, and became thereby changed into the absorber. The condenser at the same time became the vaporizer or refrigerator, and after receiving a mold containing water to be frozen, was securely wrapped with non-conducting material. Apparatus of this kind is only fitted for work on a small scale, and is inefficient. An adaptation of Carre's apparatus has been used in refrigerator cars for carrying perishable freight. In the car are placed two receptacles, one containing liquid ammonia, which maintains a low temperature by vaporization, and the other containing water to absorb the ammonia as it is formed. At the end of the route, or when necessary, the receptacles are recharged, one with liquid ammonia, and the other with fresh water. The ammonia in the rejected solution is regained by distillation.

Vacuum Refrigerating Apparatus. — A form of absorption apparatus uses water for the volatile liquid and concentrated sulphuric acid for the absorbent. From the fact that vapor of water at freezing point has a very low tension, such apparatus are called vacuum apparatus. The first apparatus of this kind was designed for freezing water in carafes, and consisted of a good air-pump, and a receptacle containing oil of vitriol. The carafe, well wrapped in non-conductor, was attached to a pipe leading to the sulphuric acid receptacle, the pump was worked till a good vacuum was produced, and the acid was stirred to present fresh acid to the vapor, which rapidly streamed from the water at the low pressure produced. The vaporization of about one-sixth of the weight of the water was found to be sufficient to freeze the remainder.

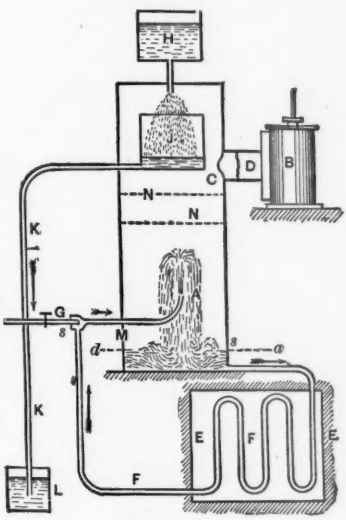


FIG. 7.

An ideal sketch of a continuous vacuum apparatus is shown by Fig. 7.

At *B* is an air-pump, capable of producing a vacuum of one or two mm. of mercury in the chamber *AC*. At *H* there is a tank of concentrated sulphuric acid, from which a spray is delivered at *J*. The acid absorbs the vapor formed in the chamber at the low pressure existing there, gathers in the tank *J*, and flows out through the pipe *K*, which is of sufficient length to deliver the acid against atmospheric pressure in the tank *L*. The dilute acid is reconcentrated and returned to tank *H*. At *G* is a pipe supplying fresh water, which passes through the water injector *s*, and throws a jet of salt solution into the chamber at *A*. The finely divided jet looses fresh water by vaporization, is chilled, and gathers in the bottom of the chamber. The salt solution flows through the pipe *F* in the cold chamber *EE*, taking up heat on the way, and is again thrown into the chamber with a fresh supply of water from the pipe *G*. At *N* and *N* are screens to prevent splashing of water into the upper part of the chamber.

CONDENSATION OF BENZYL CYANIDE AND ITS SUBSTITUTION PRODUCTS WITH ALDEHYDES AND WITH AMYL NITRITE.

By HOWARD V. FROST, S.B., Ph.D.

Note. — The following is a translation of article in the *Annalen der Chemie*, Band 250, p. 156. The work was done in Göttingen.

In the course of his work over benzyl cyanide and its derivatives obtained by substitution, Professor Victor Meyer needed a method by which the benzyl cyanide itself could be separated quickly from its homologues formed by substitution in the methylen group, which have quite the same properties. In the experiments undertaken for this purpose, he found two reactions, which, on account of their smooth way of taking place, required further study.

If one mixes benzyl cyanide with oil of bitter almonds and adds Claisen's means of condensation, — an alcohol solution of sodium ethylate, — the mixture solidifies after quite a short time, forming crystals of the product

$$C_6H_5 - CH = C(C_6H_5) - CN$$

(α phenylcinnamic acid nitrile).

The action of nitrous acid on benzyl cyanide is almost quantitative in its results, and not less elegant than the foregoing reaction.

Also, here the reaction was brought about through Claisen's means of condensation.

If benzyl cyanide, amyl nitrite, and sodium ethylate are mixed, there is formed, under strong evolution of heat, a crystalline mass of the combination

$$C_6H_5 - (CN)C(=NONa).$$

The first of these reactions has served frequently since that time for the separation of benzyl cyanide from its homologues formed by substitution in the methylen group (which are thereby not at all attacked).

The second takes place with homologues in a complicated way and has been studied hitherto only with benzyl cyanide itself.

The closer study of the products formed by these two reactions, as well as the extended use of the reactions on other aldehydes and on dif-

ferent derivatives of benzyl cyanide and benzoic aldehyde, was handed over to me by Professor Victor Meyer.

The following are the results of my investigations.

BENZYL CYANIDE AND ALDEHYDES.

a Phenylcinnamic Acid Nitrile.

About 5 cb. cm. of a twenty per cent sodium alcoholate solution were added to a mixture of 10 grms. benzyl cyanide and 9.5 grms. benzoic aldehyde under shaking. Under lively evolution of heat there separated out, almost instantly, a white crystalline mass, which after a short time was placed on a filter, washed with distilled water, then with ordinary alcohol, in order to remove any unchanged benzyl cyanide and benzoic aldehyde.

The substance crystallizes out of boiling alcohol in white, leaf-like crystals. The crystals, after being pressed and dried over sulphuric acid, showed the melting point 86°; the boiling point lies at 359–360° (corr.). The nitrile is insoluble in cold and hot water, slightly soluble in cold alcohol, and easily soluble in ether, carbon bisulphide, chloroform, benzol, and hot alcohol.

I. 0.2428 grm. substance gave 0.7806 grm. carbonic acid gas and 0.1201 grm. water.

II. 0.2062 grm. substance gave 12.2 cb. cm. moist nitrogen, at 16° and 755 mm. pressure.

	Calculated for $C_6H_5-CH=C(C_6H_5)-CN$.	Found.
Carbon	87.8	87.7
Hydrogen	5.37	5.5
Nitrogen	6.83	6.85

In order to characterize the above nitrile, as an unsaturated combination, the bromine and chlorine addition products of the same were produced.

Bromine Addition Product.

In a carbon bisulphide solution the nitrile took bromine on easily, and changed itself over into a white crystalline powder, which when heated became brown and melted soon afterward at 129–130°.

0.2212 grm. gave, according to Carius, 0.2267 silver bromide.

	Calculated for $C_6H_5-CHBr-CBr(C_6H_5)-CN$.	Found.
Bromine	43.84	43.58

Chlorine Addition Product.

By saturating the carbon bisulphide solution of the nitrile with chlorine gas, and allowing it to stand several days, the chlorine addition product was obtained in the form of white needles, which melt at 167–168°.

0.3208 grm. gave, according to Carius, 0.325 silver chloride.

	Calculated for $C_6H_5-CHCl-CCl(C_6H_5)CN$.	Found.
Chlorine	25.73	25.07

By the saponification of the nitrile with alcoholic potash, the *a* phenylcinnamic acid was obtained. Its melting point was observed at 167°, while the same ought to lie at 169–170°. The difference can be explained, on the grounds that the reaction does not take place smoothly, and that much resinous matter is formed, from which the acid itself cannot be separated completely.

Furfurol and Benzyl Cyanide.

Benzyl cyanide furnishes with furfurol, under the influence of Claisen's reagent, *a* phenyl-furfuracrylic acid nitrile, which melts smoothly at 42–43°, and corresponds to the *a* phenylcinnamic acid nitrile in its general properties.

0.306 grm. gave 19.05 cb. cm. moist nitrogen, at 6.5° and 744 mm. pressure.

	Calculated for $C_4H_3O-CH=C(C_6H_5)-CN$.	Found.
Nitrogen	7.18	7.42

The addition of bromine takes place in a carbon bisulphide solution, under lively evolution of heat. The addition product appears in orange-colored six-sided plates, which melt at 113–114°.

0.2312 grm. gave, according to Carius, 0.2456 silver bromide.

	Calculated for $C_4H_3O-CHBr-CBr(C_6H_5)CN$.	Found.
Bromine	45.07	45.20

The analogous chlorine addition product could not be obtained, in spite of repeated trials, and by the saponification of the above *a* phenyl-furfuracrylic acid nitrile only resinous products were formed.

Anisic Aldehyde and Benzyl Cyanide

furnished, in the same way, the *a* phenyl-derivative of the anisacrylic acid nitrile, which appears in white needles of melting point 93°. The same resembles in regard to its properties both of the foregoing condensation products.

0.211 grm. gave 11.1 cb. cm. moist nitrogen at 6° and 749½ mm. pressure.

	Calculated for $C_6H_4(OCH_3)-CH=C(C_6H_5)-CN$.	Found.
Nitrogen	6.0	6.3

The bromine and chlorine addition products of this nitrile could not be obtained; also the *a* phenylanisacrylic acid, in pure form, could not be obtained by the saponification of the same.

Metanitrobenzoic Aldehyde and Benzyl Cyanide.

The condensation product, obtained from these, was yellow and crystalline, the melting point of which is 133–134°.

0.2026 grm. gave 19.8 cb. cm. nitrogen, at 14° and 753½ mm. pressure.

	Calculated for $C_6H_4(NO_2)CH=C(C_6H_5)-CN$.	Found.
Nitrogen	11.2	11.4

The bromine addition product, belonging to the above, is a straw-colored crystalline easily decomposable powder, which melts at 127–128°, under evolution of bromine.

0.3222 grm. gave, according to Carius, 0.2916 silver bromide.

	Calculated for $C_6H_4(NO_2)-CHBr-CBr(C_6H_5)-CN$.	Found.
Bromine	39.02	38.52

Orthonitrobenzoic Aldehyde and Benzyl Cyanide

furnished the analogous combination in compact yellow needles, melting at 127–128°.

0.2239 grm. gave 24.1 cb. cm. nitrogen, at 9° and 753½ mm. pressure.

	Calculated for $C_6H_4(NO_2)-CH=C(C_6H_5)-CN$.	Found.
Nitrogen	11.2	11.5

By treating this *a* phenylorthonitrocinnamic acid nitrile with bromine, there was obtained an uncrystalline product out of alcohol; but because the same showed no smooth melting point (bromine being evolved in the vicinity of 129°), no analysis was undertaken.

Paranitrobenzoic Aldehyde and Benzyl Cyanide.

The corresponding paracombination was obtained as an orange-colored powder, melting at 117–118°.

0.2092 grm. gave 19.9 cb. cm. nitrogen, at 13° and 754 mm. pressure.

	Calculated for $C_6H_4(NO_2)-CH=C(C_6H_5)-CN$.	Found.
Nitrogen	11.2	11.16

Trials to add bromine or chlorine onto this paraderivative remained resultless; therefore it appears that of the three *a* phenylnitrocinnamic acid nitriles, only the metacombination reacts smoothly in this sense.

Benzoic Aldehyde aud Parabrombenzyl Cyanide

react smoothly with each other, forming a crystalline condensation product, which separated out of an alcohol solution in leaf-like scales, melting at 111–112°.

I. 0.2846 grm. gave 12.4 cb. cm. nitrogen, at 18° and 742 mm. pressure.

II. 0.2865 grm. gave, according to Carius, 0.1905 silver bromide.

	Calculated for $C_6H_5-CH=C(C_6H_4Br)-CN$.	Found.
Nitrogen	4.93	4.92
Bromine	28.17	28.31

Furfurol and Parabrombenzyl Cyanide.

A crystalline combination was obtained very easily from these, appearing in fine silky glistening needles, having a melting point of 65°.

I. 0.282 grm. gave 13.3 cb. cm. nitrogen, at 17.5° and 746 mm. pressure.

II. 0.264 grm. gave, according to Carius, 0.18 grm. silver bromide.

	Calculated for $C_4H_3O-CH=C(C_6H_4Br)-CN$.	Found.
Nitrogen	5.11	5.35
Bromine	29.19	29.01

The addition of bromine takes place very quickly with the above *a* parabromphenylfurfuracrylic acid nitrile; the combination, so obtained, crystallizes in brown glistening needles, and melts, under evolution of bromine, at about 212°.

0.2882 grm. gave, according to Carius, 0.3728 silver bromide.

	Calculated for $C_4H_3O-CHBr-CBr(C_6H_4Br)-CN$.	Found.
Bromine	55.3	55.03

Anisic Aldehyde and Parabrombenzyl Cyanide

furnished a condensation product in the form of needles, which melt at 135°.

I. 0.2982 grm. gave 11.8 cb. cm. nitrogen, at 16° and 748 mm. pressure.

II. 0.2756 grm. gave, according to Carius, 0.1662 silver bromide.

	Calculated for $C_6H_4(OCH_3)-CH=C(C_6H_4Br)-CN$.	Found.
Nitrogen	4.46	4.53
Bromine	25.48	25.66

The trials, in order to add bromine onto this last compound, *a* parabromphenylaniscrylic acid nitrile gave a remarkable result. The nitrile, dissolved in carbon bisulphide, was allowed to stand one week with excess of bromine in closed flask at the temperature of the room. The mixture was then shook with soda solution to remove the excess of bromine, and after being washed with water evaporated. The residue was again treated with soda solution, and finally crystallized out of dilute alcohol.

Flat yellowish needles were deposited, which melt at 186°.

0.2978 grm. gave, according to Carius, 0.2852 silver bromide.

	Calculated for $C_6H_4(OCH_3)-CHBr-CBr(C_6H_4Br)-CN$.	Found.
Bromine	50.63	40.77

A second analysis gave the same per cent of bromine. The latter corresponds closely with a combination $C_{16}H_{11}NOBr_2$, which requires 40.71 per cent Br. By the continued heating of the above bromine compound with sodium alcoholate, no recognizable amount of sodium bromide was formed; therefore an atom of Br. has not been added to the CH group because it could be eliminated therefrom, but rather must have been substituted in one of the phenyl rests; therefore one of the following combinations was formed:—

$$C_6H_3Br(OCH_3) - CH = C(C_6H_4Br) - CN$$

or

$$C_6H_4(OCH_3) - CH = C(C_6H_3Br_2) - CN,$$

whose per cent of bromine, of 40.71, corresponds accurately with what was found, namely, 40.77.

Isonitrosobenzyl Cyanide.

Equivalent weights of benzyl cyanide and amyl nitrite, 10 grms. of each, corresponding to the equation

$$C_6H_5CH_2CN + C_5H_{11}ONO + C_2H_5ONa$$
$$= C_6H_5C = NONa \cdot CN + C_5H_{11}OH + C_2H_5OH,$$

were mixed and placed in a cooling mixture. A theoretical amount of sodium alcoholate, 2 grms. sodium dissolved in 20 grms. absolute alcohol, was added. Immediately a transposition took place, accompanied with a considerable evolution of heat, and the light yellow sodium salt separated out so abundantly that finally the whole mixture solidified into a crystalline mass. The latter was placed on a filter, washed with alcohol and a little water, and then dried over strong sulphuric acid. Thus prepared, it appeared as a yellow powder, which is easily soluble in water and quite easily in alcohol.

0.1713 grm. substance gave, after evaporation with chlorhydric acid in crucible and glowing, 0.0594 sodium chloride, corresponding to 13.53 per cent sodium.

	Calculated for $C_6H_5-(CN)C=NONa$.	Found.
Sodium	13.69	13.53

For further characterizing, the acid that is the free isonitrosobenzyl cyanide was prepared from the sodium salt.

This free isonitrosobenzyl cyanide was prepared some time ago in the Göttingen laboratory by Alexander Meyer, who found that it is easily soluble in alcohol, ether, and hot water, crystallizes out of water

in beautiful white scales, which melt at 129°. I have prepared the free isonitrosobenzyl cyanide in the foregoing way, and have confirmed completely the above statements.

The potassium salt was obtained by means of potassium alcoholate, by the same method as the sodium salt. It is easily soluble in water, only a little in ordinary alcohol, and is easily decomposed.

0.1968 grm. substance gave, after evaporation with chlorhydric acid in crucible and glowing, 0.080 potassium chloride, corresponding to 21.3 per cent potassium.

	Calculated for $C_6H_5-(CN)C=NOK$.	Found.
Potassium	21.2	21.3

The copper salt was obtained as a bluish green precipitate by addition of copper sulphate solution to an aqueous solution of the sodium compound.

The copper salt was insoluble in water and easily decomposed.

0.1795 grm. substance gave, after glowing, 0.04 copper oxide, corresponding to 17.83 per cent of copper.

	Calculated for $(C_6H_5-(CN)C=NO)_2Cu$.	Found.
Copper	17.96	17.83

The lead salt separated out, as a white precipitate, as an aqueous solution of the sodium salt was added, drop by drop, to a solution of the ordinary lead acetate, which is used as a reagent.

0.2354 grm. substance gave, after glowing with sulphuric acid and a little ammonium carbonate, 0.1973 lead sulphate, corresponding to 57.3 per cent lead.

	Calculated for $(C_6H_5-(CN)C=NO)_2Pb+PbO$.	Found.
Lead	57.5	57.3

While the isonitrobenzyl cyanide may be considered as a strong acid, on account of its great capability of forming salts with the alkalies and heavy metals; yet it was impossible to form the pure methyl ether and acetyl derivative from the metallic salts.

Parabrombenzyl Cyanide and Amyl Nitrite

furnished, in the presence of sodium alcoholate in an analogous way, the sodium salt of the parabromisonitrosobenzyl cyanide, as a light yellow amorphous substance.

0.3026 grm. of the latter gave 0.0852 sodium sulphate.

	Calculated for $C_6H_4Br-(CN)C=NONa$.	Found.
Sodium	9.31	9.12

On the addition of acid to the aqueous solution of the sodium salt, the free parabromisonitrosobenzyl cyanide separates out in the form of white scales, which melt at 131–132° and dissolve easily in alkalies, forming a yellow solution.

0.3150 grm. gave, according to Carius, 0.264 silver bromide.

	Calculated for $C_6H_4Br-(CN)C=NOH$.	Found.
Bromine	35.56	35.65

The silver salt was precipitated from the aqueous solution of the sodium salt by means of silver nitrate, as an amorphous light yellow powder, insoluble in water.

0.1876 grm. gave 0.061 g. silver.

	Calculated for $C_6H_4Br-(CN)C=NOAg$.	Found.
Silver	32.53	32.51

In a similar way the copper salt was precipitated by a copper sulphate solution, as an amorphous green powder, insoluble in water.

0.247 grm. gave, according to Carius, 0.1805 silver bromide.

	Calculated for $(C_6H_4Br-(CN)C=NO)_2Cu$.	Found.
Bromine	31.28	31.10

Lastly, it is to me a most agreeable duty to express my gratitude to Herrn Geheimrath Professor Victor Meyer, for the friendly assistance which he has given me at all times in the course of this investigation.

GAUTIER'S POCKET TELEMETER.

BY A. G. ROBBINS AND JAMES H. STANWOOD.

THE official Journal of the French Army of April 16, 1868, gives an account of an instrument invented by M. Gautier, a captain of artillery, which is designed for the rapid measurement of distances.

We have endeavored herein to give a detailed account of the construction of this instrument, the method of using it, and the results of our own experiments, together with those of as many others as we could obtain.

Fig. 1

Fig. 2

The determination of the distance to an inaccessible point necessitates the solution of a triangle of which we know one side and two angles. For example, in the right triangle ABC (Fig. 1),

$$\frac{AB}{AC} = \sin C \quad \text{or} \quad AC = AB\frac{1}{\sin C}.$$

Suppose, now, that B is not a right angle, but slightly less. Let ADC (Fig. 2) be a right angle.

Now

$$AC = \frac{AD}{\sin C};$$

but

$$AD = AB\cos BAD,$$

and

$$AC \text{ therefore} = \frac{AB}{\sin C} \cdot \cos BAD,$$

or

$$AC = \frac{AB}{\sin C} - \frac{AB}{\sin C}(1 - \cos BAD).$$

If we take for the value of AC the first term only, or $\frac{AB}{\sin C}$, we are in error by an amount equal to a fractional part of $\frac{AB}{\sin C}$, represented by $1 - \cos BAD$. By a similar reasoning, it can be shown that the result would be the same if the angle ABC were obtuse.

Now, let the angle ABC differ from 90° by 1°, 2°, 5°, 8°, or, what is the same thing, let the angle BAD equal 1°, 2°, 5°, 8°, and observe how much our assumed value of AC differs from the true value, in each case.

Nat. cos 1° = .99985, 1 − cos 1° = .00015;
Nat. cos 2° = .99939, 1 − cos 2° = .00061;
Nat. cos 5° = .99619, 1 − cos 5° = .00381;
Nat. cos 8° = .99027, 1 − cos 8° = .00973.

The term neglected is less than 1 per cent of the distance, even when the angle *BAD* is as large as 8°. We can therefore determine the distance *AC*, within less than 1 per cent, provided we can, first, determine an angle at *B*, which shall not differ from a right angle by more than 8°; second, determine the factor $\frac{1}{\sin C}$ by observation; third, measure the line *AB*.

Let us assume that the first and third operations can be readily done; we then have only to obtain the factor $\frac{1}{\sin C}$. The pocket telemeter is designed to measure this quantity.

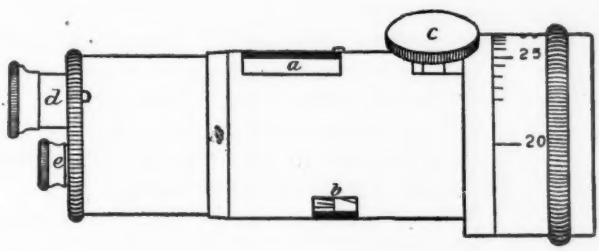


Fig. 3

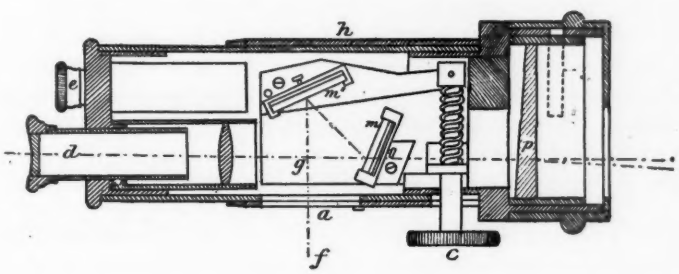


Fig. 4

NOTE. — Telescope *d*, or the eye-piece *e*, can be placed in front of the mirrors at the will of the observer. The ring *h* can be revolved so as to close the openings *a* and *b* to exclude dust.

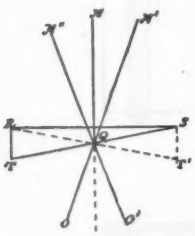
This instrument, shown in outline in Fig. 3 and in cross-section in Fig. 4, consists of a tube of about two inches greatest diameter, and five inches in length. At *mm'* are two small mirrors, occupying the lower half of the tube. The mirror *m* is fixed in position, but the one at *m'* is connected with the screw *c*, so that the angle between the mirrors can be varied a small amount either side of 45°. An opening *a* in the side of the tube allows a ray of light, coming in the direction *f*, to be seen through the telescope *d* after being doubly reflected by the mirrors *mm'*. The angle *fgd* is 90° or slightly more or less, according as the angle between the mirrors is 45° or slightly more or less.

An opening in the under side of the instrument, shown in Fig 3 at *b*, shows on a graduated plate the amount that the angle of the mirrors differs from 45°.

At *p* is a glass prism, firmly cemented to a ring capable of being revolved about the end of the tube, and carrying on its outer surface a scale graduated from 20 to ∞.

Let *RST* (Fig. 5) be a section of this prism. A ray of light coming from *M* and striking the prism normal to *RS* is not deflected, but on leaving the prism at *Q* it is deflected in the direction *QO*, so that the point *M* would be seen in the direction *OM'*. Suppose that we revolve the prism through 180°, so that it takes the position *RST'*. A ray of light coming from *M* will now be deflected in the direction *QO'*, and would be seen in the direction *O'M''*.

Fig. 5



By revolving the prism, the point *M* can be seen in any direction between the extremes *QM'* and *QM''*. The prism is so constructed that a half-revolution displaces the image about 3°, or, in other words, the angular displacement of the prism is sixty times greater than that of the image. Thus we can measure small angular displacements of the image with great accuracy.

The graduation on the ring carrying the prism gives the values of $\frac{1}{\sin C}$, *C* being the angular displacement of the rays of light caused by revolving the prism. As these graduations vary from 20 to ∞, the angular displacement can vary from 0° to 2° 51′ 58″ about, since

$$\frac{1}{\sin 0°} = \infty, \quad \text{and} \quad \frac{1}{\sin 2° \, 51' \, 58''} = 20.$$

Method of Using. — Let C (Fig. 6) be any object, and AC the distance to be found. The observer at A first places the ∞ mark opposite the index on the fixed part of the tube (when thus placed the position of the prism is as shown in Fig. 4), and holding the instrument with the opening a (Fig. 4) on the right side, looks in the direction AM and sees, by double reflection, the object C at C'; looking over the mirrors, through the prism, he selects some prominent object M in line with AC'. He next goes to B in the line AM, and again observes the object M. By double reflection the image of C is seen at C'', to the left of M, the angle CAC' being equal to CBC''.

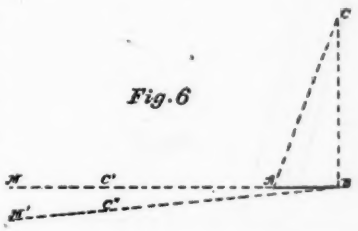


Fig. 6

By revolving the prism the light coming from M is deflected to the left, and coincidence can again be established, M being seen at M', in the direction BC''. The division on the graduated scale opposite the index gives $\frac{1}{\sin MBM'}$, which is equal to $\frac{1}{\sin ACB}$. This quantity multiplied by the base AB gives the distance AC sought.

Generally there will be no prominent object at M exactly in the direction of the reflected image of C. In this case the observer selects one from the prominent objects nearly in line, and by turning the screw at c slightly, alters the angle between the mirrors mm', and brings the reflected image of C in line with the object selected.

It is preferable to select some object to the left of C', rather than one to the right, making the angle CAC' slightly greater than a right angle. In so doing the angle CBC', which can be from 0° to about 3° less than CAC', will be very nearly a right angle, and we make the error, caused by assuming CBC' to be 90°, as small as possible.

Instead of taking a fixed base AB, it is sometimes advisable, after observing at A, to set the instrument at some fixed value of $\frac{1}{\sin C}$, say 50, and to then move backward on the line MA until the coincidence, destroyed by turning the prism, is again brought about. Then measure the base gone over, which will be one-fiftieth of the distance AC.

By this method the errors caused by interpolating between the divisions are avoided. It is also found true in practice that the best results are obtained when the value of $\frac{1}{\sin C}$ is from 50 to 75.

If the object C is not very prominent, it may be difficult to see it by double reflection. In cases like this it is better to observe the point C directly through the prism. The observer at A (Fig. 7) looks at C through the prism. At the same time objects in the direction of M will be seen by double reflection at M' in the line AC (if the angle between the mirrors is properly adjusted). He then goes to B and then sees the reflection of objects at M, at M'', to the left of C. By revolving the prism until C is seen at C′ coincidence is again established, and the value of

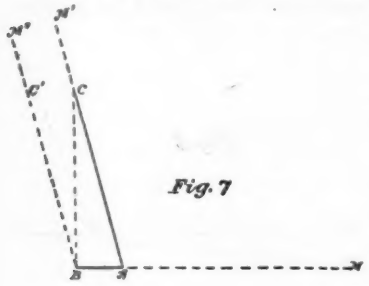


Fig. 7

$$\frac{1}{\sin CBC'} = \frac{1}{\sin ACB}$$

is obtained. This multiplied by AB gives AC as before.

When only a short base can be used, good results may be obtained by a method of repetition. This is done by taking a series of observations, alternately, at each end of the base; coincidence of direct object and reflected image being established at one end by altering the angle between the mirrors, and at the other end by revolving the prism. If n observations are taken, and a represents the length of the base, the distance sought is

$$na \times \frac{1}{n \sin C}.$$

In this case, as in the others, it is advantageous to have the last reading exactly at one of the graduations. This may be done by using a constant base for all but the last observation, and then setting the instrument at the next less division and measuring the base necessary to establish a coincidence of direct object and reflected image.

Thus, if with a 10-foot base, nine observations have been taken, and then the instrument is set at the next less division, which is (say) 50, and we find the length of base necessary to give that reading to be 9.5 feet, the distance is

$$(9 \times 10 + 9.5)\ 50 = 4975 \text{ feet.}$$

Error in the Alignment of the Base. — Suppose that at the extremities of a base of 69 feet, the last station be taken at one-tenth of a foot outside the alignment on the signal, at B' (Fig. 8). The error of alignment of the base is measured by the angle BAB', which is about five minutes in the case assumed. The pocket telemeter determines the angle C by the difference between the angles MAC and MBC. If the observer is at B′, he measures the difference of the angles MAC and $MB'C$; the error which he makes is therefore

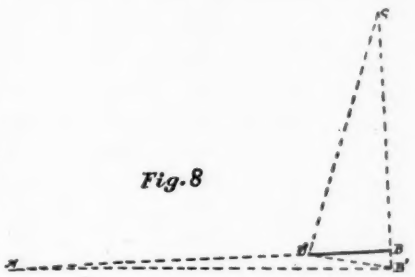


Fig. 8

$$MBC - MB'C = BMB',$$

the value of the angle C being too great by that amount, and the distance AC obtained will be a little less than the true distance.

The contrary would be true if the point B' were between B and C.

This error of the angle is, according to the above, in the inverse ratio of MB to AB, so that if the distance of the signal M from the first station is equal to ten times the base (690 feet in our assumed case), the error in measuring the angle C is less than one-tenth of five minutes or thirty seconds. If the distance of the signal M is sixty times the base, this error becomes less than five seconds.

This example shows that it is advantageous to employ a distant signal, and that when the distance to the signal M is necessarily short, great care must be taken in the alignment of the base in order to insure good results.

The following results, published by the inventor, were obtained by the commissioners appointed to examine this instrument in France: —

Base Employed.*	Factors Read.	Distances Found.	True Distances.	Errors.	Designation of Objects.	Remarks.
Metres.		Metres.	Metres.	Metres.		
20	30	600	600	0	Battery	Dark and rainy
20	35	700	715	−15	"	"
20	50	1000	1000	0	End of Polygon	Fine weather
20	64	1280	1240	+40		"
20	80	1600	1600	0	Hospital	"
20	110	2200	2190	+10	Church	"
40	64	2560	2580	−20	Hospital	"
49.8	54	2689	2660	+29	Tower	High wind
168.5	21	3538	3510	+28	Church	Fine weather
68.5	57	3904	3880	+24	Convent	"
39.2	100	3920	4050	−130	House	High wind
32.9	131	4310	4260	+50	Tree	Fine weather
58.65	80.5	4722	4650	+72	Village	"
88.0	58.5	5148	5100	+48	Observatory	"
36.25	160	5800	5920	−120	Castle	High wind
40.0	165	6600	6580	+20	Staff	"

* Bases were measured with a tape.

Base Employed.*	Factors Read.	Distances Found.	True Distances.	Errors.	Designation of Objects.	Remarks.
Metres.		Metres.	Metres.	Metres.		
42	23	966	943	+23	Bridge	Fine
40	44	1760	1750	+10	Church	"
19	21	399	400	−1	Tower	Fine, but after sundown
28	21	588	600	−12	"	"
18	37	666	680	−14	Bridge	"
32	22	704	710	−6	"	"
43	20	860	880	−20	Convent	"
36	125	4500	4400	+100	Point	"
20	45	900	880	+20	River Bank	"
19	70	1330	1320	+10	R. R. Bridge	Violent squalls
20	70	1400	1440	−40	Fortification	"
32	54	1728	1750	−22	"	"
15	130	1950	2020	−70	"	"
10	320	3200	3100	+100	Belfry	"
60	60	3600	3600	0	Hospital	"
80	62	4960	5000	−40	Obelisk	"

* Base measured by pacing.

The following experiments were made at various times by observers here at the Institute, most of them by persons having no previous experience in using the instrument.

GIVEN MULTIPLE AND BASE FOUND.

Base.	Factor.	Distance Found in Feet.	Error.	True Distance.
213.16	60	12,790	−327	Distance scaled from map = 13,025 feet.
188.94	70	13,226	+109	
165.30	80	13,224	+107	
148.68	90	13,381	+264	
133.51	100	13,351	+234	
214.28	60	12,857	−260	
185.11	70	12,958	−159	
164.31	80	13,145	+28	

The average of these distances = 13,117.

CONSTANT BASE AND MULTIPLES READ.

Base.	Multiple.	Distance Found in Feet.	True Distance.	Errors.
200	64	12,800	13,025	−293
190	68	12,920		−173
170	78	13,260		+167
150	89	13,350		+257
190	67	12,730		−363
150	90	13,500		+407

Average of 14 observations, 13,105.

NOTE. — In the above tables the error is obtained from the average of distances found, instead of from scaled distance.

In the following experiments the base was measured, and the true distance sought was 3400 feet.

Base.	Multiple.	Distance Found.	Error.	Base.	Multiple.	Distance Found.	Error.
100	33	3300	100	25	137	3425	25
"	33	3300	100	"	140	3500	100
"	33	3300	100	"	139	3475	75
"	32	3200	200	"	140	3500	100
"	33	3300	100	10	360	3600	200
"	33	3300	100	"	380	3800	400
"	33	3300	100	"	350	3500	100
"	32.75	3275	125	"	375	3750	350
"	33	3300	100	"	330	3300	100
"	33	3300	100	"	360	3600	200
50	68	3400	0	"	350	3500	100
"	69	3450	50	"	380	3800	400
"	67	3350	50	10*	67	3350	50
"	68.5	3425	25	"	70	3500	100
"	68	3400	0	"	65	3250	150
"	67.5	3375	25	"	66	3300	100
25	138	3450	50	"	65	3250	150
"	140	3500	100	"	66	3300	100

* Method of repetition used: five observations taken at each end of base.

A very complete description of the pocket telemeter is found in "Notice sur le Télémètre de Poche," par A. Gautier, Paris. Librairie Militaire de J. Dumaine.

It is briefly treated by Gen. F. A. P. Barnard in "Report on the Industrial Arts," published by Van Nostrand; and in Knight's "American Mechanical Dictionary."

The instrument is manufactured by M. Tavernier-Gravet, No. 19 Rue de Mayet, Paris.

MASSACHUSETTS INSTITUTE OF TECHNOLOGY,
April 2, 1889.

THE INFLUENCE OF TEMPERATURE ON THE SPECIFIC ROTATION OF CANE SUGAR.

By CLEMENT W. ANDREWS, A.M.

THE statement of Tuchschmid,* that the specific rotation of pure sugar solutions is independent of the temperature, has been generally accepted. I was surprised, therefore, to find that the test of the hundred points of several saccharimeters, both color and half-shade, gave a lower result the higher the temperature at which the test was made. Allowance was made, of course, for the change in the density of the solution and in the length of the tube, and also in the specific rotation of the quartz wedges.

I have been able to find but few investigations of the subject. In 1842 Mitscherlich† stated that the rotatory power of cane sugar is not much altered by change of temperature. In 1843 Ventzke‡ found that the angular rotation of a cane sugar solution is the same at 80–85° C. as at ordinary temperatures, and since the density decreases, he supposed that the specific rotation increases with the temperature. In 1846 Dubrunfaut§ stated that a sugar solution loses 0.04 of its original rotation at 19° C. when heated to 80° C. Correcting for the expansion of the solution and of the brass tube, he calculated that the specific rotation of cane sugar at 100° is less than at 0° by 0.0232 of the amount at the latter temperature. Tuchschmid‖ found that the observed decrease in the angular rotation of a 25 per cent solution between 10° and 40° C. was very nearly equal to that calculated from Gerlach's figures for the decrease in density, and stated that the specific rotation is independent of the temperature. His conclusions are based on the mean of 40 readings at each of the two temperatures, but the separate readings show a deviation from the mean in each case of ± 0°.3 on a total value of about 18°. Also, in calculating the angle which he ought to find, supposing the specific rotation to be constant, he did not determine the specific gravity, but used Gerlach's figures for a solution of 23.7 for his solution of 24.9 per cent, and assumed that the change from 10° to

* Journal für praktische Chemie, 1870, (2) **2**, 245.
† Berlin Akademie Berichte, 1842, 150.
‡ Journal für praktische Chemie, **28**, 101.
§ Annales de chimie et de physique, (3) **18**, 101. ‖ *loc. cit.*

40° is proportional to that from 10° to 27°.5. The error affects the calculation of the difference in the angular rotation but slightly, but it makes the absolute amount too small, and increases the apparent purity of the sugar.

In 1875 Hesse* published a series of determinations of the specific rotation of cane sugar for sodium light, showing the effect of concentration. Of these, two made at 25° showed the same rotation as two of the same strength at 15°, but the largest angle observed, 13°.3, and the range in temperature, were too small to make the results of any value in this connection. This is the latest work on the subject that I have found, and none is mentioned in Landolt's recent review of polariscopic analysis.†

A repetition of these experiments, made with more delicate instruments, has resulted in a confirmation of Dubrunfaut's statement of the decrease of the specific rotation with increase of temperature, though the amount per degree is somewhat less than was stated by him. They were made with a Laurent large-model polariscope, made in Paris, reading to 30ths of a degree, and permitting the estimation of minutes. The lamps, for sodium light, were those furnished with the instrument. I found them, when properly adjusted, less liable to variations in intensity of light than a single Muencke burner.

The observation tube was of brass, double walled, with openings at each end into the outer tube, and one in the middle into the inner one. The ends were carefully prepared plane surfaces at right angles to the bearings. The length was determined with the Rogers comparator in the Physical Laboratory of the Institute, by comparison with the Rogers standard bar. The comparator reads to 0.00001 inch, and gives 0.0001 inch with ease. A series of eight measurements on different parts of the circumference of the ends gave a mean of 15.7703 inches, with a maximum deviation from it of 0.0002. On reduction to millimeters, and correction for temperature, the length at 20° C. was found to be 400.577 mm. The end plates were tested with a gauge and found to be of sensibly equal thickness in all parts. The caps simply slipped over the ends of the tube, as in the new Landolt tubes, thus avoiding all chance of polarization by the end plates through unequal or excessive pressure.

The weights used had been recently adjusted by Becker, and their total weight compared with the standard kilogram at Washington. All weighings were made by substitution and reduced to weight in vacuo.

The calibration of the flask and pyknometer was done with distilled

* Annalen der Chemie, **176**, 97.

† Berichte der deutschen chemischen Gesellschaft, 1888, **21**, 191.

water, correcting for temperature and displacement of air by Table 17 of Landolt and Börnstein's Physikalisch-chemische Tabellen. All temperatures recorded or used were measured with a standard thermometer recently tested by the Physicalisch-technische Anstalt at Charlottenburg.

The arrangement used for heating the tube was very similar to that employed by Tuchschmid; the current of water passing through the outer tube being warmed in a large mass of water. At no time during an observation was there any distortion of the field or of the line between the halves.

The angular measurements are the means of not less than six readings, made alternately from right and left, of the zero, of the angle in the right semicircle, of the same in the left semicircle, and of the 180° point. The observations were made in the evening, without disturbing light.

The sugar used was prepared by solution of the best refined sugar, filtration, precipitation by alcohol, washing with alcohol, and drying at 65° C. Ten grams of this sugar lost 0.0007 gram on being heated several hours in the water bath, and left less than 0.001 gram on ignition. It gave no test with Fehling's solution. Its purity was further shown by its specific rotation, which was 66°.398 at 20° C. for a solution of $c = 26.01$. Landolt's formula, calculated from the latest and best determinations, requires 66°.421 for the given concentration. The difference is about the average difference between the formula and the determinations from which it was computed.

The solution used in the first experiment was intended to be a Ventzke standard solution; *i.e.*, to contain, at 17°.5 C., 26.048 grams, weighed in air, in the volume of 100 grams of water, in air, at that temperature, or 26.004 grams, in vacuo, in 100 true cubic centimeters.* The actual weight, in air, of the sugar was 26.066 grams, and of the solution 110.010 grams, giving on reduction to weight in vacuo 23.686 per cent of sugar.

With this solution two sets of readings were made at 18° and two at 41°. The dew point was too high to permit reading much below 18°. In the following table the angles are the mean of six readings of the solution and the zero: —

	Temp.	Right semicircle.	Left semicircle.	Mean.	
1. . .	18°.2	69° 13′.2	69° 21′.0	69° 17′.1	or 69°.285
2. . .	18°.8	69° 6′.7	69° 11′.7	69° 9′.2	" 69°.153
3. . .	41°.3	68° 22′.2	68° 29′.3	68° 25′.75	" 68°.429
4. . .	41°.0	68° 26′.5	68° 31′.8	68° 29′.15	" 68°.486

* See the next paper, p. 374.

In calculating the specific rotation, 1 and 2 were combined, and 3 and 4, giving 69°.219 at 18°.5 and 68°.458 at 41°.15. It is evident that the variations of the separate readings from these means are due in part to two causes which are compensated for in taking the mean; viz., the difference in the temperature and a slight eccentricity of the graduated circle and the optical parts of the instrument. Yet without considering this compensation, the greatest deviation of a single reading from the mean is +0°.218 for 1 and 2, and −0°.155 for 3 and 4. On a total rotation of 18° these would be +0°.06 and −0°.04 respectively.

The specific rotation was calculated by the formula

$$[\alpha]^t_D = \frac{100\,\alpha}{l \times p \times d},$$

in which

α = angle observed, in degrees;

l = length of tube, in decimeters;

p = percentage of sugar, by weight in vacuo;

d = specific gravity of the solution at temperature of observation, water at 4° C. being unity.

The values are given below: —

	t.	α.	l.	p.	d.	$[\alpha]_D$
I. . . .	18.5	69.219	4.0057	23.686	1.09842	66.415
II. . . .	41.15	68.458	4.0074	23.686	1.08987	66.174

Dividing the difference in the specific rotation, 0.241, by the difference in the temperature, 22.65, gives 0.0106 as the mean change in the specific rotation per degree Centigrade.

To check this result a second experiment was made with another preparation of sugar and a different concentration. In this experiment the weight of sugar taken was 16.3096 grams, in air, and that of the solution 106.2540 grams, giving on reduction to weight in vacuo 15.344 per cent of sugar. This solution contains, at 17°.5, 16.30 grams in 100 cubic centimeters, and is very nearly a standard solution for the Soleil-Dubosq and Laurent saccharimeters. The rotation was determined first at 19°, then at 39°.9, and finally at 20°.1. The angular measurements given below are the means of ten readings of the solution and the zero: —

	Temp.	Right semicircle.	Left semicircle.	Mean.
1. . .	19°.0	43° 30′.9	48° 26′.1	43° 28′.5 or 43°.475
2. . .	39°.9	43° 5′.0	43° 0′.8	43° 2′.9 " 43°.048
3. . .	20°.1	43° 31′.1	43° 27′.2	43° 29′.15 " 43°.486

The greatest variation of a single reading from the mean was 0°.062, or 0°.03 on 18°.

The specific rotation was calculated from the following data:—

	t.	*a.*	*l.*	*p.*	*d.*	$[a]_D^t$
1. . . .	19.0	43.475	4.0057	15.344	1.06139	66.642
2. . . .	39.9	43.048	4.0073	15.344	1.05430	66.405
3. . . .	20.1	43.486	4.0058	15.344	1.06127	66.664

The values of $[a]_D$ in 1 and 3 are somewhat larger than the 66.53 required by Landolt's formula for this concentration at 20°. The difference, however, is not greater than has been observed by Tollens for the same solution at different times. If not caused by a difference in the sugar, it may be due to more white light in the sodium flame; it certainly is not due to momentary changes, such as differences of intensity of light on the half-disks, because all the zero and 180° point determinations vary less than a minute. On the other hand, the close agreement between 1 and 3 shows that the lower value in 2 is not due to inversion or other permanent change in the solution. In calculating the influence of temperature 1 and 3 were combined, giving 66°.653 at 19°.55. Dividing 0.248 by 20.35 gives the change per degree as 0.0122. The agreement between this and the first determination is so close that there should be no serious error in taking the mean of the two and expressing the relation of the specific rotation to the temperature by the formula:—

$$[a]_D^t = [a]_D^{20} - 0.000114\ (t-20).$$

If 66.5 is taken as a mean value for $[a]_D^{20}$, the coefficient of change per degree centigrade is 0.000171. This is somewhat smaller than that obtained by Dubrunfaut, 0.000232; but it is for a smaller range of temperature, and it is possible that the rate of change may be greater at a higher temperature.

NOTES ON THE DETERMINATION OF SUGAR BY THE POLARISCOPE.

BY CLEMENT W. ANDREWS, A.M.

1. *Influence of Temperature.* — In practical optical saccharimetry it is generally assumed that the change in density is the only cause of error due to differences in temperature, and this is allowed for in one of two ways. Either the solution is made at a known temperature and the temperature of observation determined, or, more conveniently and generally, the solution is read at as nearly as possible the same temperature as that at which it was made. Other causes of error, however, can materially affect the result. Thus Anders * has called attention to the error due to unequal heating of the ends of the instrument. His remedy for this was the clumsy and inaccurate one of removing the lamp after every observation; it is evident, however, that the frequent reading of the zero now so strongly urged, and a sufficient distance between lamp and instrument, are better safeguards.

Again, King † has called attention to the necessity of reading solutions containing any considerable amount of invert sugar at a fixed or known temperature because of the great influence of temperature on the specific rotation of that substance. Its influence on that of cane sugar also is too large to be neglected in accurate work where there is any considerable difference between the temperature of observation and that at which the instrument was graduated, and the same may be said of its influence on the rotation of the quartz wedges in the instruments using them. The errors due to these causes, except the last, may be avoided by the use of a jacketed tube; all solutions being made up and read at the temperature at which the saccharimeter was graduated. Unquestionably this method gives the most accurate results, but it is inconvenient for rapid work, so that I have calculated the factors by which the observed reading should be multiplied to obtain the true reading. In this calculation the coefficient of the cubical expansion of glass has been assumed as 0.000025 and that of the linear expansion of brass as 0.000019. The change in the specific rotation of the solution was found from the formula $1 - 0.000171\ (t - 17.5)$, and that of the quartz from Sohncke's formula $1 + 0.0000999t + 0.00000318t^2$. The

* Zeitschrift des Vereines deutscher Ingenieure, **10**, 321. † Chemical News, **48**, 229.

actual expansion of a 23.7 per cent solution was calculated from Gerlach's figures for the apparent expansion of 20 and 25 per cent solutions.

In the table, column 1 gives the factors for a solution made and read at $t°$, in an instrument without quartz wedges; column 2 for the same read against quartz; column 3 for a solution made at 17°.5 and read at $t°$ directly; column 4 for the same read against quartz.

$t.$	1.	2.	3.	4.
10	0.9987	0.9978	0.9970	0.9961
15	0.9996	0.9993	0.9990	0.9987
17.5	1.0000	1.0000	1.0000	1.0000
20	1.0004	1.0007	1.0011	1.0014
25	1.0013	1.0022	1.0035	1.0044
30	1.0022	1.0036	1.0060	1.0074
35	1.0031	1.0051	1.0086	1.0106
40	1.0040	1.0067	1.0114	1.0140
Mean change per degree from 17.5 to 40	0.00018	0.00030	0.00051	0.00062

Although these factors have been calculated for the Ventzke standard solution in brass tubes, they can be used for other solutions and glass tubes without serious error. The difference between glass and brass tubes is 0.0002 at 40°, while Gerlach's figures give the difference between the expansion of a 25 per cent and that of a 15 per cent solution as 0.0005 at 40°.

That the corrections here given are not too large will be seen from a comparison of the reading of a standard solution on several different saccharimeters at different times. The solutions were prepared by weight and the readings are the means of a large number of observations. The first column gives the actual reading at the temperature given; the second, these readings corrected by Matecgzek's table for density alone; the third, the same corrected by the factors given above.

	$t.$	1.	2.	3.
1. C. S. color	23	99.77	99.92	100.10
2. C. S. color	23.2	99.79	99.94	100.12
3. C. S. color	25.4	99.67	99.88	100.13
4. C. S. color	24.4	99.46	99.64	99.86
	27.9	99.39	99.68	100.00
5. S. & H. color	28	99.23	99.52	99.85
6. S. & H. shade	29	99.11	99.43	99.78
Mean			99.72	99.98
Greatest variation from 100			0.57	0.22

2. *Standard Solutions.* — The Ventzke standard solution is usually spoken of as one containing 26.048 grams in 100 cubic centimeters. The greater delicacy of modern saccharimeters renders necessary greater precision of statement, and it should be defined as containing, at 17°.5 C., 26.048 grams of pure sugar, weighed in air with brass weights, in 100 Mohr cubic centimeters; *i.e.*, in the volume of 100 grams of distilled water at that temperature. This is not only the solution used in practice and by the makers in graduating the saccharimeters; it is also the solution supposed to correspond to the former standard specific gravity, 1.1000. The original Ventzke solution * was one of specific gravity 1.1056, or 25 per cent by weight, in a tube 234 mm. long, having a rotation of 56° for the red ray matching a given solution of anilate of iron. In fact, the graduation of Ventzke's earlier saccharimeters was based on the last quantity, 56° being divided into 100 parts. Apparently on adopting Soleil's improvements, the bi-quartz, wedges, and color compensator, and certainly between 1847 and 1857, the standard solution was changed to one of specific gravity 1.1000 read in a 200 mm. tube. I have not been able to find an original statement of this change, or of the supposed equivalent of the new standard solution, 26.048 grams in 100 cc. The latter is evidently taken from the Brix-Balling tables † of the specific gravity of sugar solutions. In these tables the percentage by weight corresponding to the specific gravity 1.1000 is 23.68, which multiplied by 1.1 gives 26.048. But Balling does not mention reduction to weight in vacuo, and the specific gravities in these tables, as well as in those of Neimann originally used in Ventzke, are referred to water at 17°.5 C. as unity, so that the true interpretation is that the standard solution of specific gravity 1.1000 contains 26.048 grams, weighed in air, in the volume of 100 grams of water at 17°.5. Whether this statement is absolutely correct, or not, is immaterial, since the newer saccharimeters are understood to be graduated on the latter basis and not on that of specific gravity. That the use of Mohr flasks in saccharimetry is generally understood in Germany may be seen from the statements of Jena,‡ Scheibler,§ Tollens,‖ Schmitz,¶ Landolt,** and Schmidt and Haensch.††

* Journal für praktische Chemie, **25**, 67, 81.

† Verh. Ver. Bef. Gewerbefleisses Preussen, 1854, 132; Landolt und Börnstein, Physikalisch-chemische Tabellen, p. 152.

‡ Post's Chemisch-technische Analyse, 1882, p. 692, 704.

§ Zeitschrift Verein Rübenzucker-Industrie, **17**, 210, in Zt. anal. Chemie, 1867, 617.

‖ Berichte der deutschen chemischen Gesellschaft, **10**, 1403; **11**, 1800. ¶ *Ibid.*, **10**, 1414.

** Annalen der Chemie, **190**, 307, and Ber. d. c. G., **21**, 195.

†† Gebrauchs-Anweisung zu den Polarisation Apparaten, Berlin, 1887, p. 13.

Indeed, any mention of the matter would be superfluous if the text-books and authorities in English did not fail to recognize the custom. Allen* gives no directions for graduating the flasks; Tucker† gives for the 100 cc. flask the volume of 99.89 grams of water at 16°; Landolt,‡ 99.875 grams in air at 17°.5; and a committee of the National Academy§ have taken as the standard solution one containing 26.048 grams, in vacuo, in the volume of 100 grams of water, in vacuo, at 4° C., or about 26.032 grams, in air, in the volume of 99.775 grams, in air, at 17°.5. The difference between this solution and the one accepted in Germany is, therefore, nearly 0.2 per cent. It is evident that if the reduction to weight in vacuo were intended, the standard weights furnished would be 26.032 and not 26.048 grams, while unless this reduction is made the reduction to 4° is meaningless.

In this connection some facts in regard to the use of the Mohr cubic centimeter may be of interest. An examination of the books on analytical chemistry at hand leads to the conclusion that it is used generally in Germany and the United States, commonly in England, and apparently not at all in France. The books may be divided into three classes, according as the cubic centimeter is defined as the volume of a gram of water in air at some ordinary temperature, in air at 4°, or in vacuo at 4°.

In the first class are: —

Bolley, Technisch-chemische Untersuchungen, ed. 4, by Kopp, 1874, p. 20.
Church, Laboratory Guide, ed. 2, 1870, p. 97.
Dittmar, Quantitative Chemical Analysis, 1887, p. 19.
Fleischer, Volumetric Analysis, ed. 2, tr. by Muir, 1877, p. 18; and Muir, p. 23.
Fresenius, Anleitung zur quantitativen chemischen Analyse, ed. 6, 1875, I., p. 35.
Hart, Volumetric Analysis, 1878, p. 24.
? Medicus, Massanalyse, 1883, p. 17.
Mohr, Titrirmethode, ed. 4, p. 39; ed. 6 by Classen, 1886, p. 41. Also in French, tr. by Forthomme, 1857, p. 33.
Post, Chemisch-technische Analyse, 1882, p. 692.
Rieth, Volumetrische Analyse, 1883, p. 8.
? Schmid, Sanitarisch- und polizeilich-chemische Untersuchungen, 1878, p. 6.
Sutton, Volumetric Analysis, ed. 5, 1886, p. 18.
Winkler, Praktische Uebungen in der Maassanalyse, 1888, p. 19.

In the second class: —

Cairns, Quantitative Chemical Analysis, 1880, p. 3.
Fresenius, Anleitung etc., ed. 5, 1867, p. 33, and American ed., 1888, p. 13.
Hoppe-Seyler, Physiologisch- und pathologisch-chemische Analyse, ed. 4, 1875, p. 12.

* Commercial Organic Analysis, 1886. † Sugar Analysis, 1884, p. 178.
‡ Handbook of the Polariscope, 1882, p. 183.
§ Annual Report for 1887, p. 43.

In the third class: —

Appleton, Quantitative Chemical Analysis, ed. 3, 1881, p. 43.
Jagnaux, Analyse chimique, 1888.
Muter, Analytical Chemistry, 1887.
Thorpe, Quantitative Chemical Analysis, ed. 5, 1883, p. 116.

In accordance with the prevailing usage, as thus shown by the text-books, the laboratories of the United States Department of Agriculture, Harvard, Yale, Columbia, and the Institute of Technology, use gram rather than cubic centimeter flasks, and those laboratories which accept the makers' graduation must of necessity do so, as practically all the apparatus sold in this country is graduated on this system. Whether the French makers apply the corrections to 4° and to weight in vacuo, I have not been able to ascertain. In view of this general agreement, it is to be regretted that the editors of the last American edition of Fresenius' Quantitative Analysis have followed the edition of 1867, without mentioning the complete change of opinion expressed in the last (1875) German edition. This change on the part of Fresenius, and the failure of Landolt's recommendation to change the custom of sugar chemists, are strong indications of the convenience of the custom.

The only other interpretation of the Ventzke scale is that of Tollens,* who makes 100° V. equal to 34°.6015 angular measurement for sodium light, and calculates the quantity of sugar necessary to obtain this as 26.068 grams in air, in 100 Mohr cc. This value of 100° V. is, however, simply the value calculated by Landolt † from Wild's determination of the specified rotation of cane sugar, and was probably never used in actual graduation of instruments. Moreover, it is too high a value, since Wild's figures were for true cubic centimeters and weight in vacuo.

The other arbitrary scale in common use, the Soleil, has been subjected to even more changes than that of Ventzke. From its original statement as the concentration necessary to produce in a 200 mm. tube the same rotation for the sensitive tint as a millimeter of quartz, its calculated or determined value will vary with the purity of the sugar, the accuracy of the determination, and the assumed or determined value of a millimeter of quartz. To these causes of variation inherent in the definition should be added the influence of temperature, the uncertainty as to the size of the flasks, and the correction to weight in vacuo, and possibly a difference between the ratios for sodium light, the sensitive tint, and the rays used in the shadow instruments for white light.

* Berichte der deutschen chemischen Gesellschaft, **10**, 1800.
† Zeitschrift für analytische Chemie, **7**, 9.

What advantage has been taken of these possibilities for disagreement will be seen from the list of standard solutions proposed: —

		Grams in 100 cc.
1846.	Clerget, Annales de chimie et de physique, (3) **26**, 175 . . .	16.471
1851.	Dubrunfaut, Comptes rendus, **32**, 249	16.395
?	Pouillet, Barreswil, Schlösing, Dubosq	16.35
1865.	Wild, Neues Polaristrobometer (Na light, true cc., weight in vacuo)	16.315
1867.	Scheibler, Zt. Ver. Rübenzucker-Industrie, **17**, 210 (in air, Mohr cc.)	16.35
1875.	De Luynes and Girard, Comptes rendus, **80**, 1354 (found $[\alpha]_D$ sugar 67°.31, quartz 21°.80)	16.19
1878.	Tollens, Berichte der deutschen chemischen Gesellschaft, **11**, 1800 (Na light, in air, in Mohr cc., quartz 21°.7189)	17.337
1879.	Landolt, Optisches Drehungsvermögen, p. 167 (calc. from Schmitz; Na light, true cc., in vacuo)	16.302
1880.	Allen, Chemical News, **42**, 177 (calc.)	16.26
1880.	Laurent, Saccharimètre Laurent, p. 11	16.2
1885.	Loiseau, Journ. fabr. sucre, **24**, 52	16.25
1886.	Sidersky, Bull. assoc. chim., **3**, 255 (calc.)	16.29
1886.	Richardson, Amer. Journ. Chem., **8**, 72 (calc.)	16.29
1887.	Kauders, Organ Oesterr. Ver., 1887, 645 (calc. from Schmitz) . .	16.315
1887.	Courtonne, Journ. fabr. sucre, 1887, 42	16.27
1889.	Gunning, Zt. anal. Chem., **28**, 45	16.26

Besides these values, Tollens * attributes to Dubrunfaut the value 15.976, and refers to a paper on the subject by Scheibler, which I have not been able to obtain.

The Laurent saccharimeter scale, however, is not based on a millimeter of quartz, but on angular degrees, 100° of the one being equal to 21° 40′ of the other. If 66°.5 is taken as a mean of the best determinations of the specific rotation of a solution of about 15 per cent, the concentration necessary to give 21° 40′ angular rotation is 16.29 grams, in vacuo, in 100 true cc. at 20°, or 16.31 grams, in air, in 100 Mohr cc. at 17°.5. This figure might have to be further modified if the optical parts of the instrument were not exactly concentric with the graduated circle.

3. *The Effect of Color on the Determinations.* — Hölzer † has shown that the determinations of colored solutions in a Mitscherlich saccharimeter, both by daylight and lamplight, are wholly unreliable, while very little difference is found in a Laurent sodium light instrument. Degener ‡ has since stated that the results of the Schmidt & Haensch half-shade saccharimeter are not affected by the color of the solution. I have not seen any extension of this statement to the Soleil-Scheibler

* Berichte der deutschen chemischen Gesellschaft, **10**, 1412.

† *Ibid*, **15**, 1932.

‡ Deutsche Zucker-Industrie, 1887, 1542.

color saccharimeter, though perhaps it might fairly be taken for granted, so that the following proof may be of some interest.

A very dark melado sugar was clarified and read as usual, testing 61.3. A second solution of the same sugar was filtered, but not decolorized. Of this 2 cc. and 5 cc. were added to two portions of a refined sugar before making up to 100 cc.; a third portion was read without any color. The results were: —

	Observed.	Calculated.
Refined sugar	99.0	—
+ 2 cc. melado solution	100.1	100.2
+ 5 cc. melado solution	101.9	102.1

The last solution was too dark to be read very accurately, yet the agreement between the observed and calculated reading is close enough to show that the presence of any usual amount of color in the solution does not affect appreciably the result.

*ON THE INFLUENCE OF SILICON ON THE DETERMINATION OF PHOSPHORUS IN IRON.**

By THOMAS M. DROWN, M.D.

The process for determining phosphorus in iron, now in most general use in the laboratories of iron and steel works, is, I think, the one proposed by Mr. Emmerton.† In this process the solution of the iron for precipitation by ammonium molybdate is effected by treating the iron with nitric acid, evaporating to hard dryness in a dish, taking up in hydrochloric acid, and driving off the greater portion of the hydrochloric acid by nitric. This procedure accomplishes, first, the destruction of all the carbonaceous matters; and, second, renders all the silica insoluble.

Experience has proved the former — the complete oxidation of the carbon — to be absolutely essential; but the explanation usually given, namely, that unless the carbon compounds are destroyed they will have a solvent action on the yellow precipitate, I am inclined to doubt. It seems to me more probable, as suggested by Mr. P. W. Shimer, that the conditions which are favorable for the oxidation of the carbon compounds ensure the complete oxidation of the phosphorus to ortho-phosphoric acid, and that the reason of the imperfect precipitation of the phosphorus, when the solution of the iron in nitric acid is directly precipitated by molybdate solution, is, that the phosphorus is not completely oxidized.

There have been many means proposed for destroying the carbon compounds — chromic acid, potassium chlorate, potassium permanganate, hydrogen peroxide, and others — which accomplish the purpose without the necessity of evaporating to dryness. The advantage of the latter method has been supposed to be that, in this way, the silica was at the same time rendered insoluble.

The statement of Klein,‡ that in the determination of phosphoric acid in basic slag it is not necessary to separate the silica, since the ammonium silico-molybdate is soluble in three per cent nitric acid, led me to try the effect of precipitating the phosphorus in a solution of

* A paper read before the American Institute of Mining Engineers at the Colorado meeting, 1889.

† Trans. Am. Inst. of Min. Eng., Vol. XV., p. 93. ‡ Chem. Zeitung, 10, 721.

pig-iron without previously evaporating to dryness. The results agreed perfectly with others obtained in the usual way after the removal of the silica, and further investigation showed that the silicon, at least in the form in which it exists when pig-iron is dissolved in nitric acid, is not precipitated by molybdate solution.

There is a very marked difference in the effect of nitric acid of different strengths on pig-iron as regards the condition of the silicon. When the acid is strong (1.2 to 1.4 sp. gr.), much of the silicon becomes gelatinous and prevents filtration, while with more dilute acid the silicon goes almost entirely into solution. In a communication to the American Institute of Mining Engineers in February, 1880,* I gave the effect of different strengths of hydrochloric acid on the silicon in pig-iron, showing that the strongest acid renders nearly all the silicon insoluble, and that weak acid dissolves it almost entirely. Generally speaking, the same is true also of nitric acid, as the following determinations show. It is interesting to note, in the following figures, that a nitric acid of medium strength dissolves more silicon than acid both stronger and weaker. The pig-iron used was a No. 1 foundry iron, with 2.42 per cent of silicon.

EFFECT OF NITRIC ACID OF DIFFERENT STRENGTHS ON THE SILICON IN PIG-IRON.

	Silicon in Graphitic Residue.	Silicon in Solution.
	Per Cent.	Per Cent.
With nitric acid of 1.4 sp. gr.	2.28†	0.14
	2.08†	0.34
" " 1.2 "	0.75†	1.67
	0.44†	1.98
" " 1.16 "	0.07	
	0.07	
" " 1.135 "	0.07	
	0.06	
	0.06	
	0.06	
" " 1.116 "	0.09	
	0.11	
With nitric acid of 1.102 sp. gr.	0.12	
	0.12	
	0.12	
	0.12	
	0.13	
" " 1.082 "	0.23	
	0.23	
	0.23	
" " 1.070 "	0.20	2.12
	0.24	
	0.27	2.14
	0.31	2.12

The solutions obtained with the use of acid of 1.4 and 1.2 specific gravity could not be filtered when concentrated, owing to the gelatinous condition of the silica. They were, therefore, largely diluted, and an aliquot portion of the solution was obtained by filtration. In this the silicon was determined.

* Transactions, Vol. VIII., p. 514. † By difference.

The solution made with acid of 1.116 sp. gr., and still more dilute, can be filtered without difficulty. The separation of gelatinous silica is not wholly a matter of strength of acid, neither is it wholly a matter of the percentage of silicon in the pig-iron. It has often been noted that different pig-irons, under identical treatment with nitric acid, will filter at different rates, and it sometimes happens that the iron with the least silicon proves the most refractory in filtering. This suggests that silicon may exist in different conditions in pig-iron, — a subject which cannot be further discussed in this paper.

Another pig-iron was tested in this series of experiments — a gray forge iron, with 0.63 per cent of silicon — with the following results: —

	Silicon in the Graphitic Residue. Per Cent.
With nitric acid of 1.2 sp. gr.	0.19
" "	0.20
" " 1.135 "	0.03
" "	0.03
" "	0.05
" "	0.06

From the foregoing it will be seen that the strength of nitric acid most favorable for the solution of pig-iron is about 1.135 sp. gr., and not 1.2, which is generally used.* In the solution thus obtained there is no tendency for the silica to separate; not until the solution has been concentrated by boiling to small bulk does the silica begin to gelatinize.

When molybdate solution is added to a solution of pig-iron obtained in this way, the phosphorus, as might be supposed, is only partially precipitated, owing to the fact that this treatment with nitric acid is insufficient to oxidize all the carbonaceous matters; or, as I prefer to believe, insufficient to oxidize all the phosphorus to orthophosphoric acid. To effect this, any of the oxidizing agents already mentioned may be used. Potassium permanganate, as recommended by Shimer,† seems to me the most convenient; but for the solution of the separated manganese peroxide I use, instead of hydrochloric acid, a small quantity of some organic substance, such as tartaric, citric, or oxalic acid, or sugar. The manganese oxide disappears almost instantly on the addition of the organic matter. After this treatment with permanganate and tartaric acid, which requires only a minute or two, the molybdate solution will give a complete precipitation of the phosphorus.

* Acid of 1.135 sp. gr. is conveniently made by diluting acid of 1.2 sp. gr. with half its bulk of water, or by diluting 1.4 acid with water in the proportion of 3 to 7.

† Trans. Am. Institute of Mining Engineers, Vol. XVII.

The following determinations were made in order to discover whether there is any tendency for the silicon in solution to be carried down with the yellow precipitate, either mechanically or as silico-molybdate. The pig-iron used was that already mentioned, containing 2.42 per cent of silicon : —

	1.	2.	3.	4.
Silicon in residue from nitric acid solution . . .	0.040	0.040	0.070	0.100
Silicon in yellow precipitate	0.030	0.050	0.012	0.012
Silicon in washings of the yellow precipitate with 2 per cent nitric acid	0.050	0.030	0.007	0.004
Silicon in filtrate from the yellow precipitate . . .	2.250	2.210	2.340	2.280
	2.370	2.330	2.429	2.396

There would thus seem to be no evidence of the formation of any precipitate of ammonium silico-molybdate.

The determination of phosphorus in pig-iron may be carried out in very much less time than is ordinarily needed if the separation of the silicon is omitted. Following is the procedure we have adopted in the laboratory of the Institute.

About 1.5 gram of the pig-iron (or more if the iron is very low in phosphorus) is treated in a covered beaker with 60 c.c. of nitric acid of 1.135 sp. gr. (If preferred, 20 c.c. of water may be first added, and then 40 c.c. of nitric acid, sp. gr. 1.2. In the latter way the action at first is a little less violent.) The beaker is heated on an iron plate until action ceases ; three minutes is usually sufficient time if the borings are reasonably fine. The solution is then filtered from the graphite into a 500 c.c. flask, and to the boiling filtrate are added 15 c.c. of permanganate solution of 5 gr. to the litre.* Boiling is continued until the pink color has disappeared, and a very few small fragments of tartaric acid are then added, which causes the precipitated manganese to go almost immediately into solution. The amount of tartaric acid need not exceed 0.1 gr., although the addition of an excessive quantity, as much as one gram, does not affect the accuracy of the results. To the clear solution 10 c.c. of strong ammonia (sp. gr. 0.90) are added to partially neutralize the free nitric acid. This amount leaves the solution still amber-colored; it should not be so far neutralized as to become wine-colored. When the solution has cooled down to 90° C., 80 c.c. of molybdate solution † are added, and the flask is closed with a rubber

* The strength of the solution is not a matter of importance; I have found the above amount sufficient. Shimer uses 10 c.c. of a solution of 20 gr. to the litre.

† Made by dissolving 100 gr. of molybdic acid in 400 c.c. ammonia (sp. gr. 0.96), and adding 1000 c.c. nitric acid (sp. gr. 1.2).

stopper, wrapped in a towel, and shaken vigorously for five minutes, as recommended by Emmerton.

From this point on the directions of Emmerton, in his paper already mentioned, are followed; namely, reduction by zinc and titration by permanganate. If fine, powdered zinc is used, it may be entirely dissolved in ten minutes, but filtration from the undissolved zinc seems generally to be preferred.

The following results were obtained in this way on the sample of pig-iron containing 2.42 per cent of silicon, in comparison with the older method of dissolving the iron in nitric acid, evaporating to dryness to separate silica, and precipitations by molybdate solution and magnesia mixture.

No. 1 Pig-Iron, containing 2.42 Per Cent Silicon.

	New Method.	Old Method.		New Method.	Old Method.
Phosphorus . .	0.272	0.284	Phosphorus . .	0.291	0.284
	0.279			0.291	
	0.290			0.278	
	0.280			0.294	
	0.291			0.293	
	0.292			0.286	
	0.289			0.294	
	0.292			0.294	
	0.297			0.288	
	0.296			0.292	
	0.289			0.288	

The rate of oxidation of the reduced molybdenum sesquioxide on exposure to the air is very slow, and is ordinarily not taken into account. Mr. J. W. Loveland found that it amounted, in this series of experiments, to 0.001 per cent of phosphorus for every ten minutes' standing before titration with permanganate. The foregoing results are all corrected with this factor. If rapidity of determination is of the first importance, a few minutes may be saved by omitting the filtering off of the graphite. Many trials show that this omission does not affect the accuracy of the results, although the removal of a foreign insoluble substance from the liquid enables one to carry out the process with greater satisfaction.

A considerable number of determinations were made by Mr. J. T. Greeley, a student at the Institute, of the phosphorus in the sample of gray forge iron containing 0.63 per cent of silicon, without filtering off the graphite. They are as follows: —

GRAY FORGE IRON, CONTAINING 0.63 PER CENT SILICON.

	New Method.	Old Method.
Phosphorus	0.620	0.632
	0.625	0.635
	0.631	
	0.640	
	0.633	
	0.627	
	0.629	
	0.645	
	0.635	

Two determinations made in the solution of the same pig-iron after filtering off the graphite, were: 0.636 and 0.631.

Further results obtained by Mr. Greeley are given below:—

BESSEMER IRON, CONTAINING 1.18 PER CENT SILICON.

	New Method.	Old Method.
Phosphorus	0.083	0.084
	0.085	0.087
	0.086	
	0.086	
	0.085	

NO. 1 PIG-IRON, CONTAINING 2.29 PER CENT SILICON.

	New Method.	Old Method.
Phosphorus	0.324	0.334
	0.327	0.330
	0.334	
	0.324	
	0.322	

The process for steel is, of course, the same as for pig-iron, except that the question of filtration from the graphite does not arise. In a sample of Bessemer steel the following results were obtained:—

	New Method.	Old Method.
Phosphorus	0.064	0.061
	0.060	
	0.061	

When one is familiar with the details of the process, a determination of phosphorus in pig-iron can be easily made in less than an hour.

I am indebted to Mr. James W. Loveland, Assistant in Chemical Analysis in the Institute of Technology, for valuable aid in this investigation; the credit for the analytical work, except as otherwise mentioned, is due entirely to him.

MASSACHUSETTS INSTITUTE OF TECHNOLOGY,
May, 1889.

THE MAGNETIC CIRCUIT: A THEORETICAL DISCUSSION, INCLUDING A FORMULA FOR MAGNETISM IN SOFT IRON.

By EDWARD COLLINS, Jr.

In this discussion it is assumed that a complete analogy exists between Ohm's law for the voltaic circuit and the law of magnetic lines of force in the magnetic circuit; that is, that the number of lines-of-force (N) is always equal to the magneto-motive-force (F) divided by the magnetic resistance (R).

Of these three quantities, N, F, and R, the first alone comes under the ordinary list of quantities in the centimetre-gram-second system, and is commonly known as "strength of field." It is necessary to express the other two in the centimetre-gram-second electro-magnetic system, and also to find their numerical relation to other quantities.

First, consider magnetic resistance, as simplest. The resistance of any cylindrical or prismatic body is equal to

$$\frac{\text{length}}{(\text{area of cross-section}) \times (\text{specific conductivity})},$$

or, in units,

$$R = \frac{L}{L^2 \times \kappa},$$

where κ is the specific magnetic conductivity, which for present purposes may be considered constant, and therefore drops out of a formula for dimensions. Hence, the dimensions of magnetic resistance are given by the equation

$$R = L^{-1}.$$

In numerical cases, of course, κ must be considered.

Next, consider magneto-motive force. Imagine a straight conductor of length L carrying a current of strength C. Then the intensity of field (I) at any point at a perpendicular distance (l) is given by the equation $I = \frac{C\phi}{l}$, where ϕ is the angle subtended by the conductor,

expressed in circular measure. Also, since I is equal to the number of lines-of-force per unit of area, then

$$I=\frac{N}{A}, \quad \text{or} \quad \frac{N}{A}=\frac{C\phi}{l}, \quad \text{or} \quad N=\frac{CA\phi}{l}.$$

But $N=\frac{F}{R}$ by the original assumption. The path of these lines of force is a circle around the conductor, and its length is therefore $2\pi l$. Hence,

$$R=\frac{2\pi l}{A}, \quad \text{and} \quad N=\frac{FA}{2\pi l}.$$

Equating these two values of N,

$$\frac{CA\phi}{l}=\frac{FA}{2\pi l}.$$

Cancelling $\frac{A}{l}$ from each, and transposing,

$$F=2\pi C\phi.$$

In this equation 2 and π are numerical constants, and ϕ is simply a function of the ratio of one length to another, and therefore drops out. From this it follows that the dimensions of magneto-motive-force are the same as those of current; that is,

$$F=L^{\frac{1}{2}}M^{\frac{1}{2}}T^{-1}.$$

For numerical cases the equation $F=2\pi\phi C$ must be used. If the conductor consists of a coil of (n) turns, $\phi=2\pi n$, and $F=4\pi^2 nC$, where C is in absolute units. This is therefore the numerical value of the magneto-motive-force tending to cause lines of force to flow through the coil, around the outside, and back again. It is independent of the shape and size of the coils, and of the special place in the coil where the magnetic circuit passes through.

As is well known, the presence of soft iron increases the number of lines-of-force. This effect is due to the lower magnetic specific resistance of iron as compared with air, or to its higher permeability, which is the reciprocal of resistance. As the permeability of iron is not a constant, but depends upon the density of the lines of force already in it, the resultant strength of field will not be proportional to the magneto-

motive-force, or to the intensity of field which would exist if the iron were removed.

Of the various formulas commonly given for magnetization, none are sufficiently general, and those which are based on theoretical considerations do not consider the magnetic circuit as such. In Lamont's formula, which is probably the best, it is assumed that the permeability at any stage is proportional to the difference between the actual intensity of magnetization and a certain maximum intensity (Z); that is,

$$\kappa \text{ is proportional to } (Z - I).$$

The formula is

$$I = Z(1 - \epsilon^{-\kappa_0 x}),$$

where κ_0 is the initial permeability and x is the exciting field. When pushed to extremes, this formula implies that the number of lines-of-force when iron is present cannot exceed a certain value, although if iron were not present, it might be increased without limit. This does not agree with facts. The same objection applies to Froelich's formula and to the various arc-tangent formulas, unless they are understood to refer only to the additional field strength due to the presence of iron.

Every substance possesses a certain property known as "magnetic susceptibility" (μ) which is related to magnetic permeability (κ) by the equation $\kappa = 1 + 4\pi\mu$.

Magnetic susceptibility is positive for magnetic, zero for non-magnetic, and negative for dia-magnetic substances. It is here assumed that this is the property in iron that is directly affected by the density of the lines-of-force in it, and not the permeability, as Lamont assumes. It is further assumed that the susceptibility at any stage is proportional to the difference between the additional intensity of field caused by the iron and a certain constant intensity; that is,

$$\mu \text{ is proportional to } Z - (I - I_a),$$

where I_a is the intensity of field which would exist if the iron were removed. If μ_0 is the initial susceptibility, then

$$\mu = \mu_0 \left\{ \frac{Z - (I - I_a)}{Z} \right\},$$

and

$$\kappa = 1 + 4\pi\mu_0 \left\{ \frac{Z - (I - I_a)}{Z} \right\}.$$

Everything is now prepared for deducing the law connecting number

of lines-of-force and magneto-motive-force in a circuit consisting partly of soft iron of uniform cross-section and partly of air or other non-magnetic substance. The following symbols will be used:

N = number of lines-of-force in circuit.
R = total magnetic resistance in circuit.
F = total magneto-motive force in circuit.
L = length of iron part of circuit.
A = area of cross-section of iron.
p = magnetic resistance of air-gap (constant).
κ = permeability of iron.
μ = susceptibility of iron.
μ_0 = initial susceptibility of iron.
Z = a certain constant previously used.
$\pi = 3.14159 + \cdots$. $\epsilon = 2.71828 + \cdots$.

First,

$$N = \frac{F}{R}, \qquad \therefore\ dN = \frac{dF}{R};$$

$$R = \frac{L}{A\kappa} + p, \qquad \therefore\ dN = \frac{dF}{\frac{L}{A\kappa} + p} = \frac{\kappa dF}{\frac{L}{A} + p\kappa}.$$

Also,

$$\kappa = 1 + 4\pi\mu_0 \left\{ \frac{Z - (I - I_a)}{Z} \right\},$$

and

$$I = \frac{N}{A}, \qquad \text{and} \qquad I_a = \frac{F}{\frac{L}{A} + p}.$$

Therefore

$$\kappa = 1 + 4\pi\mu_0 \left\{ \frac{Z - \left(\frac{N}{A} - \frac{F}{\frac{L}{A} + p} \right)}{Z} \right\},$$

and

$$dN = \left\{ \frac{1 + 4\pi\mu_0 \left[\frac{Z - \left(\frac{N}{A} - \frac{F}{\frac{L}{A} + p} \right)}{Z} \right]}{\frac{L}{A} + p \left[1 + 4\pi\mu_0 \left(\frac{Z - \left\{ \frac{N}{A} - \frac{F}{\frac{L}{A} + p} \right\}}{Z} \right) \right]} \right\} dF.$$

Only the principal steps of the integration will be indicated, as the actual operation is exceedingly cumbersome and tedious. It will be seen that the equation may be put into this form,

$$dN = \frac{a + bF + cN}{a_1 + p(bF + cN)} dF,$$

since the only variables are F and N. If x is substituted for $bF + cN$, and consequently, $\frac{dx - bdF}{c}$ for dN, the variables x and F can be separated, and the equation takes this form:

$$dF = a'dx + b'\left(\frac{dx}{x + c'}\right).$$

Integrating,

$$F = a'x + b' \log_e (x + c') + C.$$

The constant C is determined by the condition that when F is zero, N, and hence x, must be also zero. Then,

$$F = a'x + b' \log_e \left(\frac{x}{c'} + 1\right).$$

Making all the proper re-substitutions and transformations,

$$F = pN - \frac{Z(L + Ap)}{4\pi\mu_0} \log_e \left\{ \frac{F - \left(\frac{L}{A} + p\right)N}{Z(L + Ap)} + 1 \right\};$$

or, transforming again,

$$N = \frac{F}{\frac{L}{A} + p} + AZ \left\{ 1 - \epsilon^{\frac{4\pi\mu_0}{Z(L + Ap)}(pN - F)} \right\}.$$

This is the complete formula. It will be seen that N consists of one part which is equal to the number of lines-of-force which would exist without the iron, and of another part, due to the iron, which approaches a maximum value AZ as F increases. Undoubtedly the formula is more accurate than any other, but unfortunately it cannot be solved for N except in some special cases. An interesting case is where there is no air-gap ($p = 0$), and where $A = 1$, and $F = fL$ (f = force per unit of length). In this case the conditions are the same as those for which some other formulas are designed. Then,

$$N = f + Z\left(1 - \epsilon^{-\frac{4\pi\mu_0}{Z} f}\right).$$

This may be compared with Lamont's formula, written as

$$N = Z\left(1 - \epsilon^{-\frac{\kappa_0}{Z} f}\right).$$

If it is desired to use these results in connection with dynamo machines, the best equation is the following, which gives F for a desired value of N:

$$F = pN - \frac{Z}{M}\frac{(L + Ap)}{(4\pi\mu_0)} \log_{10}\left\{\frac{F - \left(\frac{L}{A} + p\right)N}{Z(L + Ap)} + 1\right\},$$

where M is the modulus of common logarithms $= .43429 + \cdots$.

This equation may be solved approximately as follows. Since F is usually small compared with N, it may be neglected in the second member, or a probable value assumed. This will give an approximate value for F, which, when used in the second member, will give a new value, sufficiently accurate for most purposes. This process can be repeated to any desired degree of precision.

It is important to note that p, the resistance of the air-space, must be taken so as to include the path of the waste lines-of-force; that is, those which pass outside of the armature, and N as used in the equations, include the waste lines-of-force. Their action is not only useless, but injurious, for they help saturate the iron and reduce its permeability.

It is also worth noticing that the effect of increasing Z, L, or p, which occur in the denominator of the exponent of ϵ in the formula for N, is to postpone and diminish the saturation effect, and thus increase the number of ampère-turns required to saturate the iron to a given extent.

In conclusion, some numerical values of N and F will be given, calculated from the last formula in such a manner as to obtain accuracy in the fifth decimal place. The magnetic circuit taken may be considered as a small longitudinal section from a dynamo machine, through field-magnets, air-gap, and armature. The following data are taken:

$A = 1$ square centimetre.
$L = 135.44$ cm.
$p = 1$.
$Z = 20000$, $\mu_0 = 50$ } values for very good iron.
$S = 2533$ = number of turns of wire in coils of field magnet.

The values of L and S are chosen so as to simplify the calculation. One ampère in a coil of 2533 turns produces a magneto-motive force of 10000.

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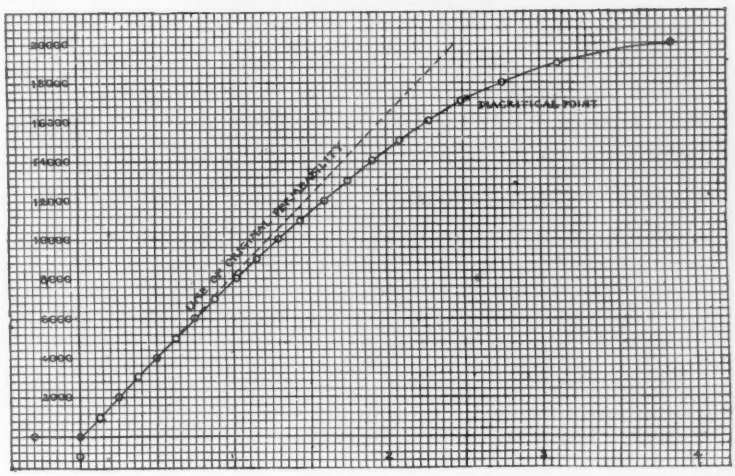

RESULTS.

N.	*F.*
1000	1220.7
2000	2453.2
3000	3698.9
4000	4959.2
5000	6236.1
6000	7531.9
7000	8849.3
8000	10190.
9000	11563.
10000	12971.
11000	14414.
12000	15917.
13000	17480.
14000	19129.
15000	20888.
16000	22812.
17000	24982.
18000	27582.
19000	31118.
20000	38505.

These results are plotted in a curve.

A rough calculation gives the "diacritical point"; *i.e.*, the point at which the magnetic conductivity of the circuit is halved, as reached when the intensity of magnetism is about 17100. As mentioned before, the location of this point depends upon the air-gap as well as upon the quantity and quality of iron. Prof. S. P. Thompson appears to have neglected the consideration of this fact in his formulas, although he alludes to it in a discussion of the influence of projecting teeth in armatures.

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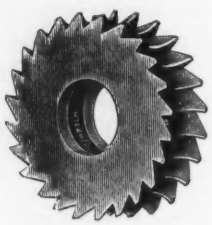

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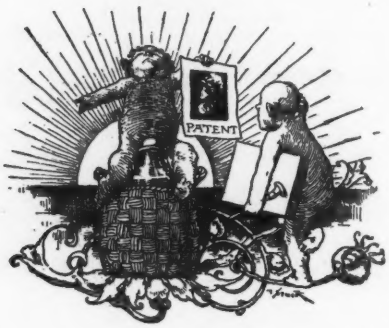

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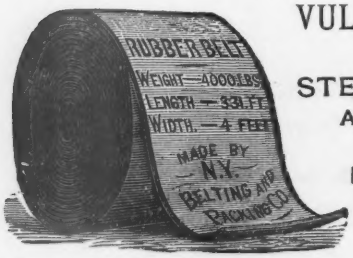

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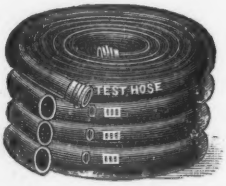

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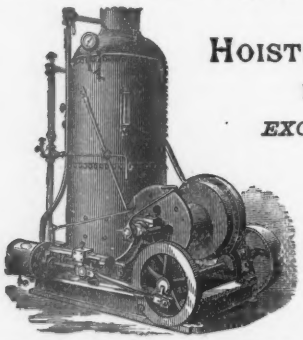

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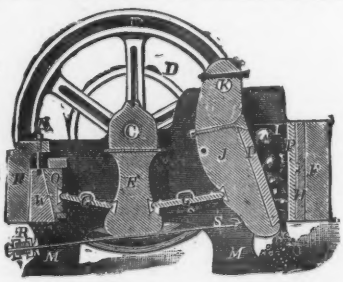

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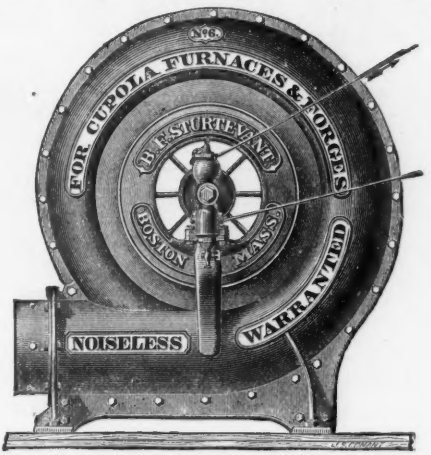

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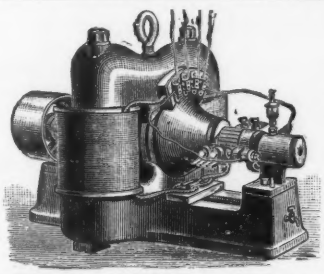

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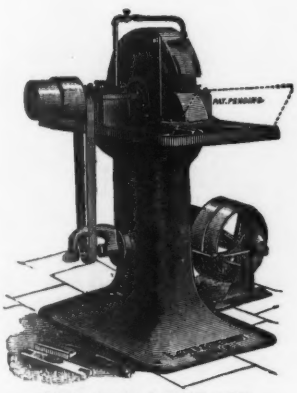

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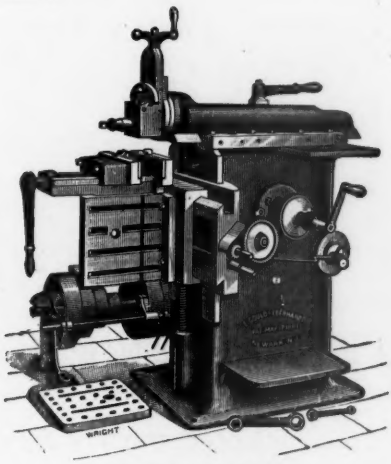

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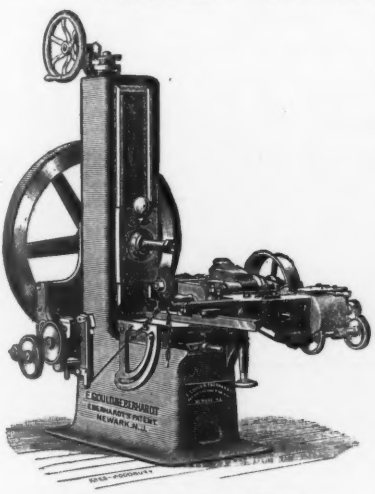

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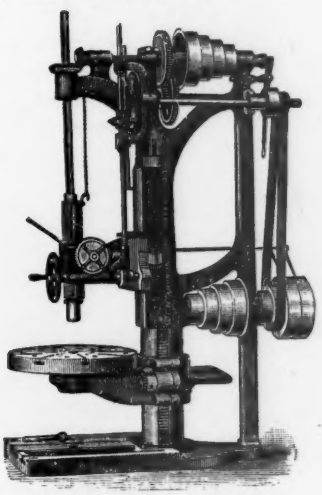

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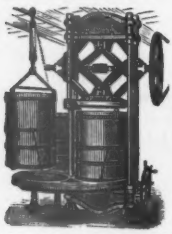

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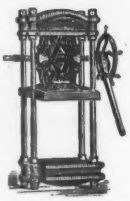

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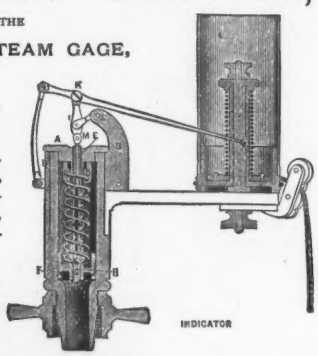

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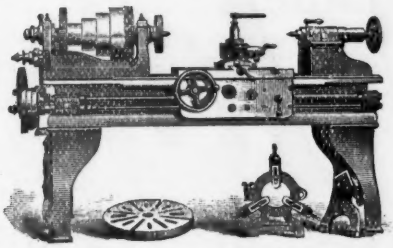

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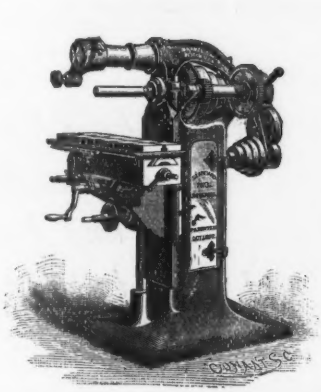

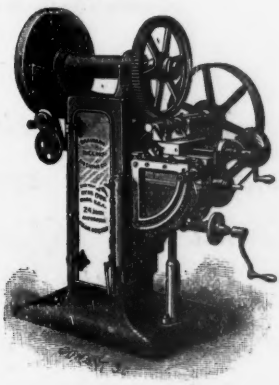

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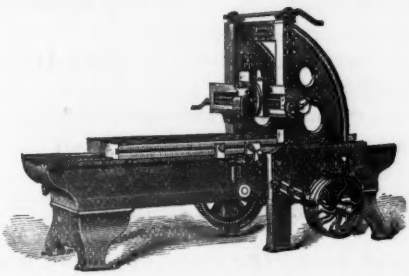

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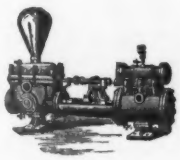

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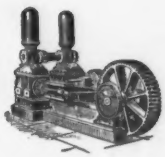

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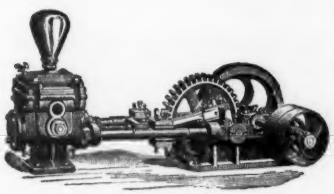

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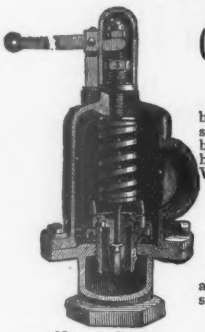

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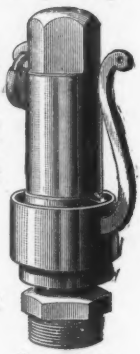

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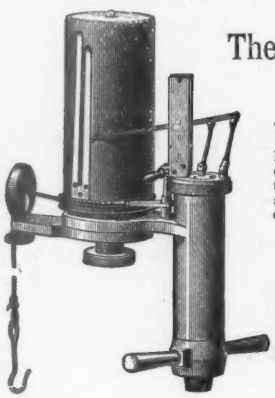

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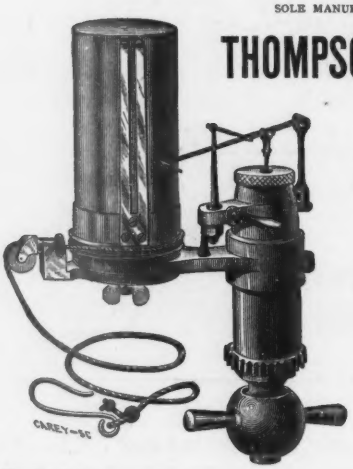

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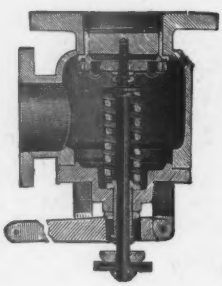

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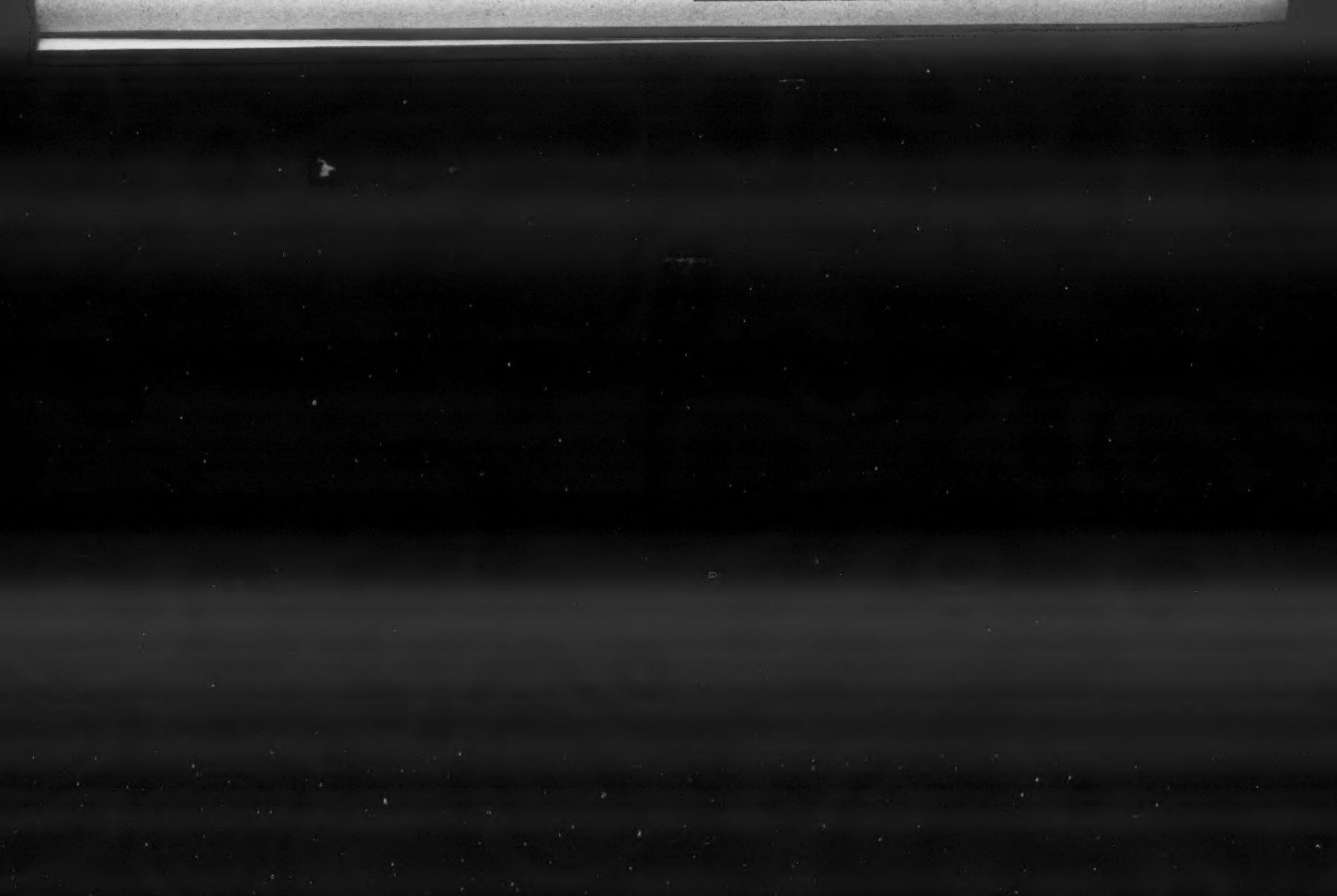

Vol. II. MAY, 1889. No. 4.

TECHNOLOGY QUARTERLY

CONTENTS

		PAGE.
On the Character and Effect of the Illuminants Present in Coal Gas	*L. M. Norton, Ph.D.*	307
A Preliminary Paper on the Drift in Portions of Middlesex County	*George H. Barton*	316
The Numbers of Bacteria in Certain City Tap-Waters	*Edwin O. Jordan*	322
Refrigerating Machines	*C. H. Peabody, S.B.*	325
Condensation of Benzyl Cyanide and its Substitution Products with Aldehydes and with Amyl Nitrite	*Howard V. Frost, S.B., Ph.D.*	349
Gautier's Pocket Telemeter	*A. G. Robbins & James H. Stanwood*	358
The Influence of Temperature on the Specific Rotation of Cane Sugar	*Clement W. Andrews, A.M.*	367
Notes on the Determination of Sugar by the Polariscope	*Clement W. Andrews, A.M.*	372
On the Influence of Silicon on the Determination of Phosphorus in Iron	*Thomas M. Drown, M.D.*	379
The Magnetic Circuit: a Theoretical Discussion, including a Formula for Magnetism in Soft Iron	*Edward Collins, Jr.*	385

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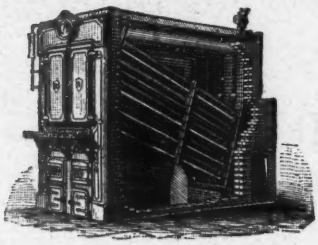

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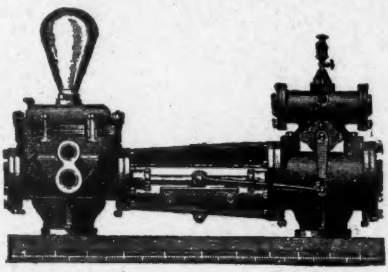

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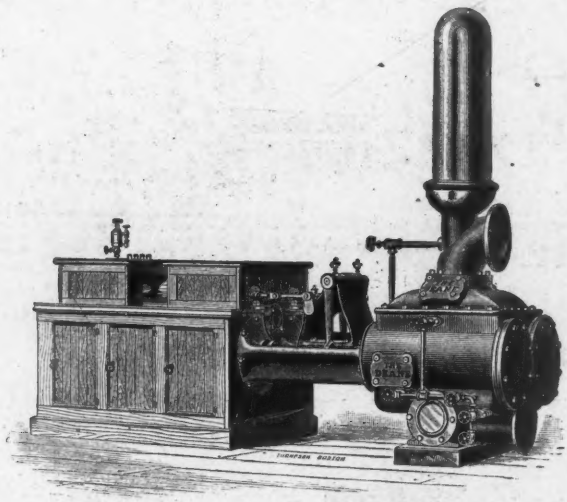

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